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Making Quantum Questions Material: 'Soft' Textile Thinking for the 'Hard' Questions Arising from an Investigation of Light

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Abstract

Paradoxical 'hard' philosophical questions and themes that confound ordinary perception arise from the question "Space, time, material, are they one with light?" posed by László Moholy-Nagy in 1917. What new forms and understandings might be revealed through an art-based investigation into the nature of light by appropriating of optical laboratory apparatus as art materials? Artistic material research contributes to illuminating the nature and properties of quantum light and the philosophical themes that arise.

Investigating quantum light reveals hidden and immaterial aspects of both light and matter and exposes the indeterminate interfaces and intrinsic interconnectedness between things, thereby questioning many assumptions and perceptions about the world—dualisms, boundaries, certainty, constancy and wholeness. The appropriation and practical exploration of optical materials used as beam-splitters in the two-slit experiments (half-silvered mirrors, diffraction grating, prisms and dichroic film) visually and experientially contribute to understanding these entwined themes. The resulting playful, illusory artworks offer multiple visual encounters simultaneously, giving access to experiences of entwined dualities, quantum superposition and entanglements.

A methodology of combining applied textile thinking (a non-linear 'soft' logic) and art processes of thinking-through-making is employed to manage the ‘hard’ complexities under investigation. Textile thinking, with metaphors of folding, interlacing and weaving, braids together many thinkers and makers from the fields of quantum physics, philosophy, Eastern metaphysics and art, highlighting the correspondences between them and emphasising where they share common ground. David Bohm's quantum theories of the implicate/explicate orders are particularly compelling, inspiring an inclusive both/and approach and a focus beyond dualistic thinking towards wholeness.

Applying textile thinking to visualising difficult scientific ideas enables multiple elements to reside within the physicality of abstract, mixed-media artworks simultaneously. The experimental art-making processes that interrogate the apparatuses through material investigations that are experiments in perception and the artworks created not only represent but phenomenologically demonstrate the bizarre and elusive nature of the quantum world for others to experience, opening up a visual language of possibilities for novel non-linear, non-dualist thinking.

Keywords: textile thinking, quantum, particle/wave duality, immaterial, diffraction, art practice, moiré, entanglement

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In addition to acknowledging the financial support from UCA, I would like to thank the tutors of the textile BA and MA courses at UCA Farnham. Within the training, Diana Harrison, Linda Brassington and Sue Harper encouraged the exacting understanding of and curiosity for the material properties of textiles and other substances which underlies this research.

I would also like to thank all the people involved in mounting exhibitions of the artworks, in particular, Loucia Manopoulou, Giuseppina Sapia, Zoe Acketts, Amak Mahmoodian, Ellie Knaggs and Chris Payne. My thanks to Helen Clarkson and the late Daniel Brant of A&D Gallery for their support, encouragement and generosity.

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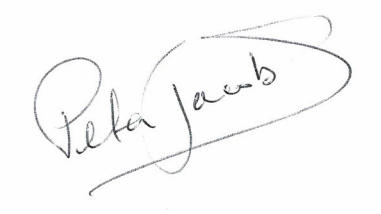
My worldview was influenced by my training in natural health and bodywork therapies which opened my eyes to Chinese medicine and awakened a holistic way of perceiving the world. I thank all these teachers, especially the late Chris Jarmey and late Don McFarland.

I would like to thank my family, Bob, Ellie, Franki and Ash for their unwavering support, encouragement and patience.

Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree, and does not incorporate any material already submitted for a degree.

Signed



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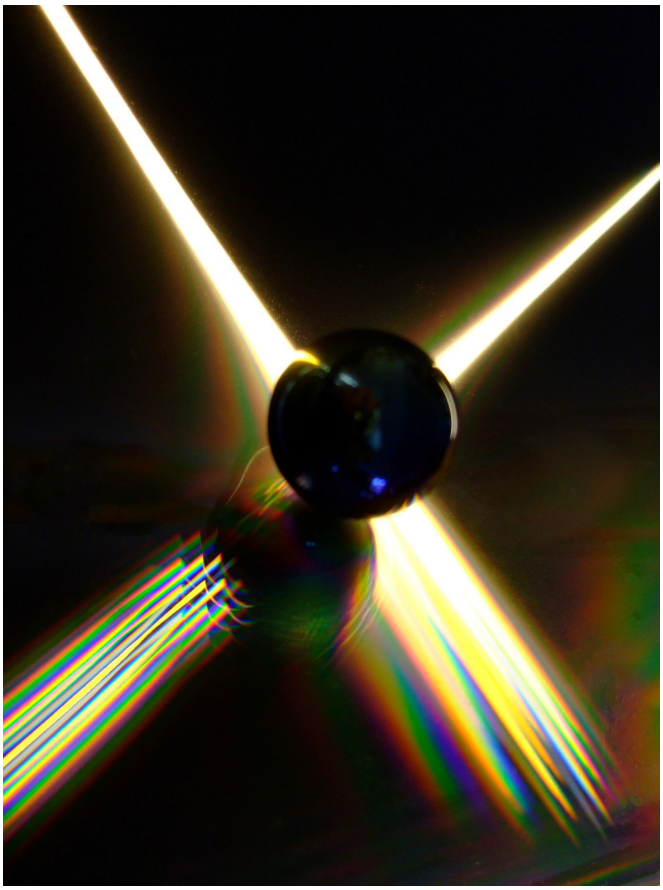

Image 1: Black paper cut with two slits, diffraction grating, black marble, LED light. 2016.

Introduction
Threading Up

Note to the Reader:

Boxed sections entitled 'Textile Notions' punctuate this text to explain and expand on some of the textile terms used. 'Notions' is a textile term used for haberdashery accessories and tools, such as buttons, ribbons and needles and pins. Textile thinking is a methodological strategy used in several ways in this research (see Chapter 4) and is a model for non-linear thinking. It manages and interlaces the many themes, art processes and materials used; moreover, textile metaphors serve to materialise the themes and ideas that are difficult to pin down, making them more accessible to others.

Textile Notion #1: Threading Up

The process of threading up a loom involves tying on the foundational, longitudinal warp threads that run through the whole length of woven cloth. Warps need to be strong enough to be held under tension so that the transverse weft threads can be drawn over and under them to create the fabric. A wide variety of threads (even very delicate, gossamer threads) can be used in the horizontal weft. When woven, the warp threads are either visible or not depending on how the fabric is structured; for example, in plain-weave cloth, the warps and wefts are equal and both are visible at the same time. However, in 'weft-facing' fabrics and tapestry weaving, all the warp threads are hidden, nonetheless, they form the supporting structure and are the framework of the cloth.

Individual warp and weft threads intersect at right angles to create a woven fabric, this interlacing of the horizontal and vertical axes is a useful model for a fundamental meeting and reconciling of polarities—a central theme and intention that runs throughout the project. Just as warp threads anchor the wefts, in this thesis, textile thinking anchors the abstract ideas which, like delicate, gossamer weft threads, are often hard to grasp firmly.

Uncontrolled threads tend to become entangled so heddles in a loom hold each warp thread separately to avoid entanglement and allow the smooth passage of the weft. (See Chapter 6 for more on entanglement.)

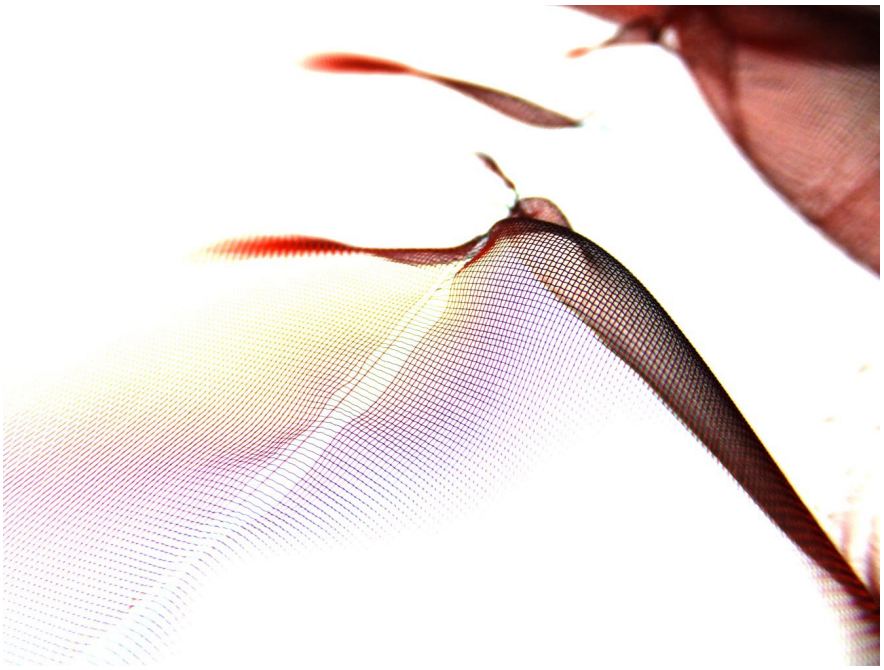

Image 2: Red organza thread with pulled thread, solarisation in Photoshop. 2021.

A methodology of textile thinking underpins this research and is discussed in *Chapter 4: Braided—Art Practice as Research and Soft Textile Thinking*. One of the contributions to knowledge that this study offers is the application of textile thinking to a visualisation of scientific ideas. This serves as a model for applying textile thinking in other fields. It is embedded in the language of the text through the use of textile metaphors, such as folding and weaving, to concretise the entwined complex ideas that emerged during the investigation of quantum light. It is also incorporated into the artistic process, through the manipulation of materials (for example, folding) and the use of recurrent motifs, such as red thread. Textile thinking manages the complexity of interweaving and integrating the many strands of scientific and philosophical thought through the multiple processes of mixed-media artmaking and serves as a model for using textile thinking in other multidisciplinary circumstances.

The guiding principle behind this research is the question that artist László Moholy-Nagy asked in 1917 in his poem, 'Light Vision', "Space, time, material—are they one with Light?" (Moholy-Nagy 1950). This research aims to disentangle and examine the complex, entwined strands of an enquiry arising from the science of light. Centring on Moholy-Nagy's poem, the initial question for this research was speculative and deliberately open, "What new forms and understandings can an art-based investigation into the nature of light reveal?" The question was not limited by an expectation of predetermined outcomes, its openness allowing scope for creative possibility.

This research seeks to uncover what artist Liliane Lijn calls "the roots of light" (2005)—not only to unfold new possibilities for aesthetic advantage but also to open up paradoxical or metaphysical questions about duality and wholeness. As the world is becoming increasingly polarised, seeking to overcome binary oppositions is a key intention behind the creation of the artworks, by unifying both polar elements of a variety of binary oppositions without relinquishing the characteristics or qualities of each, thereby offering possibilities for different thinking. To do this, several of the themes are cohesively braided together in the same artwork which, in turn, can produce new threads. In order to explore the themes and motifs further, these are then re-formed in succeeding works. By bringing the themes to material form, the outcomes of this enquiry do not produce absolute answers; instead, they seek to interrogate and re-interrogate the recurring themes that arise, raising questions and appreciating the potentiality of uncertainty, rather than providing absolute truth, presenting them in visual and experiential forms that both illustrate and demonstrate them to others.

As the research into the nature and possibilites for selected optical materials progressed, other questions arose: “What new forms and understandings emerge when engaging the

Image 3: Black paper cut with one slit, diffraction grating, dichroic film, LED light. 2018.

phenomenological characteristics of optical materials through a studio practice?" and, "Would it be possible to gain fresh understandings and insights from a questioning of the implications of themes arising from quantum physics?" Also, "Would it be possible to express difficult quantum properties experientally through the materials used in the artworks?"

Several series of investigations into optical materials (more commonly used in a science lab) presented fresh insights and new art forms, contributing to an existing body of knowledge around the collective awareness of the mysteries at the margins of our knowledge of existence that a quantum-focussed study of the properties of light reveals. Examining light through an art practice based on this led to identifying several themes that point to the nature of reality which include: the edges of becoming, unifying dualities, wholeness and the entangled relationship between the observer and observed. In this enquiry, these themes become sites of investigation and discussion and serve as the warp threads for the fabric of the research. However, like the warps in weft-faced cloth, they can often be veiled, fading back from focused view; nonetheless, they are always implicit.

Light is something we all experience; however, an extensive study of light traverses the material world into the quantum realm making light eminently suitable for investigating and expressing the elusive mysteries behind reality. Disciplinary boundaries do not constrain questions of the nature of light and no single worldview can reveal the whole truth—light inspires scientists, philosophers and artists equally. However, each perspective provides illuminating facets that serve the whole and contribute to an interwoven (but open) body of knowledge. Arthur Zajonc, a physicist concerned with quantum optics, observes that the question, 'What is the nature of light?' has been answered differently by people from various cultures and epochs (1995:38). This research focuses primarily on an artist's approach through the frame of quantum theories by using the physical qualities of light and optical materials, thereby contributing to knowledge by bringing the paradoxical, ethereal ideas to solid form.

Science undertakes to quantify reality; it offers theories and proofs explaining phenomena at the edges of becoming. Deeply probing the nature of light from a scientific perspective led to examining the bizarre and complex world of quantum physics. The quantum level of reality is a threshold where particles "hover between existence and non-existence" (Smetham 2010:23) and strange quantum properties speak of paradoxical duality and wholeness. Quantum physics is mysterious, baffling and perplexing, especially to non-scientists; nonetheless, it provides theories of phenomena at the known edges of material reality—the relationship between the seen and the unseen, material and immaterial.

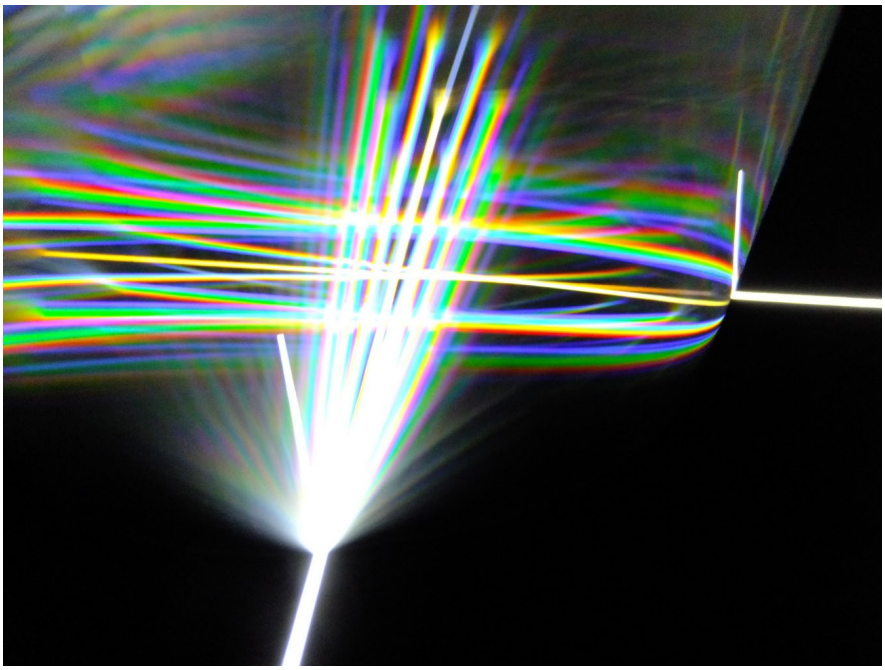

Image 4: Black paper cut with two slits, diffraction grating, LED light. 2018.

These themes, along with an understanding of underlying wholeness, are also found within metaphysics.

Paradoxically we know more of the nature of the whole by looking at the parts. Wholeness is implicit in both Einstein's theories of relativity and in quantum mechanics and is also central to David Bohm's theories of interconnected wholeness (see Chapter 7). Physically, light connects everything with everything in the universe. It travels from the far reaches of the visible universe directly into our bodies through our eyes—light is the thread that unites us with distant stars millions of light-years away. The James Webb Space Telescope reveals how light also connects us with the most distant past; astronomers have photographed galaxies formed close to the 'cosmic dawn', only 250 million years after the Big Bang which is estimated to have been 13.8 billion years ago (NASA 2022).

This research highlights correspondences between several worldviews that investigate the nature of light. Zajonc draws correspondences between quantum physics and the mysteries of both consciousness and art, proposing that light can be a tool to bridge these fields. He observes, "The mysteries of quantum mechanics, its paradoxes, wake us up to the deepest aspects of our world. Light is the bridge between these worlds" (2018:120). As an example he adds that, "there is no better guide than the artist, James Turrell" (2018:120) who acknowledges light's universal fundamental significance. Turrell proclaims, "Light is not so much something that reveals, as it is itself a revelation" (cited in Zajonc 1995:324) (see also Chapter 2).

Contextual Literature

In addition to the influence of theories arising from the physics of quantum light, the contextual literature also includes the work of light-inspired artists who are discussed in Chapter 1 and Chapter 2 and are also inserted throughout the text. Due to the entangled nature of the material in this thesis, the sources that normally would constitute a literature review are threaded throughout the text. The aim is to highlight correspondences and parallels that support the themes rather than critiquing the sources cited. The significant emphasis and influence of physics at the root of the themes raised is augmented by an associated literature that is threaded through the relevant sections. For example, a section on folding, unfolding and enfolding in Chapter 7 primarily discusses David Bohm's scientific theories of the implicate order. However, to supplement the discussions on the fold and folding Laura U. Marks' book, *Enfoldment and Infinity: An Islamic Genealogy of New Media Art* (2010) (which draws on Bohm's theories) is also discussed alongside additional sources from philosophers Gilles Deleuze and Felix Guattari and Michel Serres.

Image 5: Dichroic film, sunlight. 2018.

In addition to metaphors of folding, textile thinking has been applied across several diverse fields such as science and philosophy and this is discussed in Chapter 4: *Braided—Art Practice as Research and Soft Textile Thinking.* For example, in architecture, architects have applied models of textile thinking for its practical, inventive potential in bringing structural properties of different fabrics to bear, embracing textile tropes such as folding, felting, weaving and braiding to develop new thinking within their field (Quinn 2016:52).

The current research has been a speculative process and was not embarked upon in direct response to any previous research area in the artistic field, its scope overlaps several fields forging and contributing new forms through a visual and experiential language. As such, it is part of an ongoing quest into the hidden mysteries revealed by considering the quantum properties of light—the edges of becoming.

Outline of the Thesis

Part I—Artists in Context consists of two chapters. Firstly, *Chapter 1: Edges of Becoming—Art Inspiration* describes how the exhibition *TRA: Edge of Becoming* held during the Venice Biennale in 2011 inspired this research and how the catalogue essays, artworks and the curation of the exhibition served, in part, as models for this cross-disciplinary enquiry. The second chapter, *Light Materials—Artists and Light,* reviews selected light-inspired artists, each chosen because similarities in their practices and artworks reinforce the discoveries and positions of the current study. Artists who form a historical thread and have particular relevance to this project because light and optical materials are intrinsic to their work include László Moholy-Nagy and Liliane Lijn, both of whom were influenced by the science of light. It also includes artists, such as Larry Bell who uses materials with similar properties. The work of James Turrell and Olafur Eliasson is also discussed (Eliasson's approach to moiré is discussed more fully in Chapter 6).

Part II—Methodology consists of two chapters. Firstly, *Chapter 3: Framework and Rationale—Tangled: A Crisis of Perception,* includes an examination of the eight characteristics of Fritjof Capra's Systems Thinking, a worldview that disrupts linear thinking. The revolutionary discoveries in quantum physics supported the development of Systems Thinking by giving rise to a view that the universe is an interconnected web of relationships whose parts can only be defined through their connections to the whole (Capra & Luisi 2014:79). This view provides a useful framework for the current research, aligning with the rationale behind it.

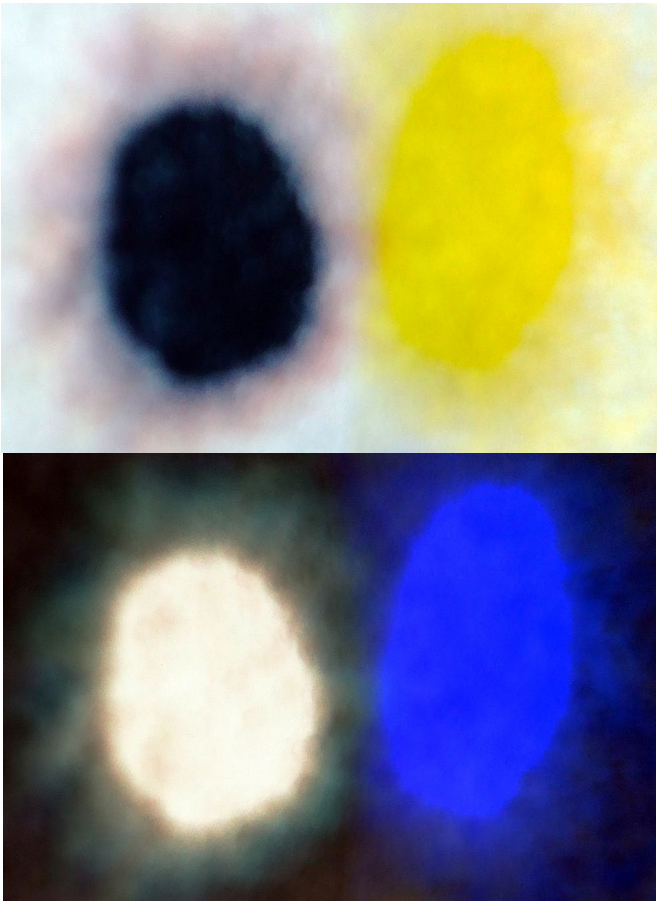

Image 6: Above: Black ink drawing, dichroic film. Below: Same photograph in negative. 2018.

The second chapter in this part, *Chapter 4: Braided—Art Practice as Research and Soft Textile Thinking,* describes how, in this enquiry, both textile thinking and art-based research are methodologies for investigating and presenting the themes and implications arising from an investigation into the nature of light and the quantum realm. Firstly, art practice is the primary site of the research. It provides cognitive alternatives to intellectual thought (through both conscious and unconscious thinking and through looking, doing and thinking-through-making) to discover characteristics and expressions of the quantum themes and produce physical outcomes for others to experience. The artworks are primary vehicles for the transmission of the discoveries to others, they embody the contribution to the field of knowledge.

The second approach to the methodology, textile thinking, underpins the (often implicit) elements of the whole research. Although the artworks made for this research are mixed-media, the approach to this research has its roots in my textile training and practice. Textile thinking is not only embedded in the language of the text and use of metaphors to incorporate and concretise complex ideas but also in the artistic process, including the use of materials and recurrent motifs. Textile thinking is a way to concretise the difficult ideas resulting from an investigation of quantum light that the research explores.

As specific scientific discoveries and theories are foundational to the ideas threaded into the artworks made for this research, the three chapters in *Part III—The Science of Light: Unravelling Threads of Influence* are devoted to describing and explaining the three main relevant scientific influences. Each chapter seeks to lay down a layman's understanding of the complex and often bizarre nature of light and its relationship to matter.

The first of these chapters, *Chapter 5: Beyond the Fringes—Quantum Light,* focuses on a description of the discovery of the wave nature of light. This is followed by a discussion of the subsequent development of the two-slit experiments. Understanding these experiments is central to this enquiry and penetrates the art practice and artwork outcomes. Many themes that have emerged from quantum physics have advanced and developed modern thinking and this is a vast and challenging field. It is necessary to limit the scope of this enquiry. Fortunately, this single set of experiments lies at the heart of quantum physics, anchoring the physics and centring the focus of this project. The experiments demonstrate that light and matter can display behaviours of both the classically defined properties of light and also the probabilistic nature of quantum phenomena. These experiments ask whether matter is fundamentally formed of waves or is composed of actual, discrete particles, or even both simultaneously and lead to questions of non-locality, entanglement (the apparent faster-than-light 'signalling' between widely separated 'entangled' particles), superposition (a particle being in two places at

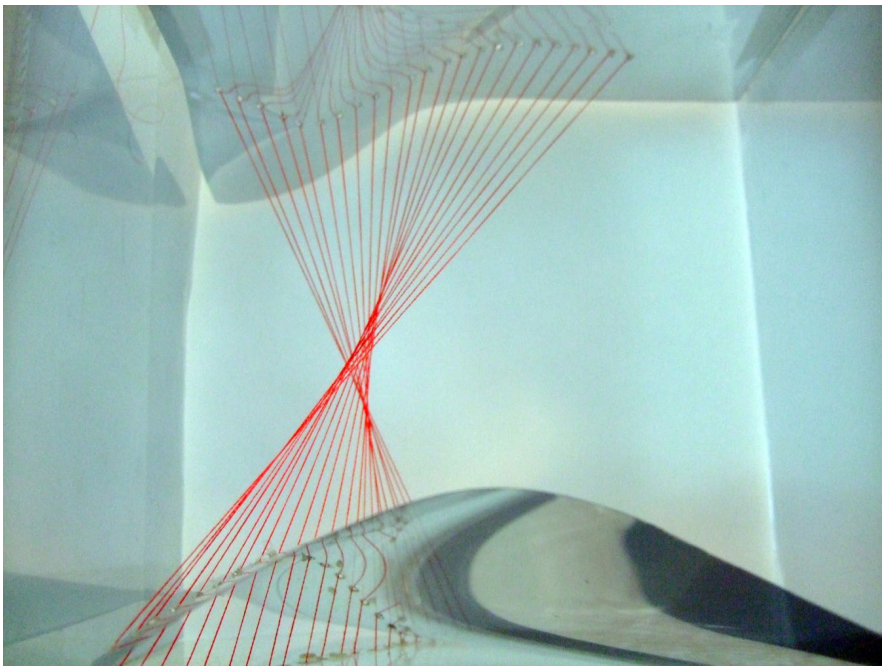

Image 7: Mirror with drilled holes, two-way mirror film, red thread. 2018.

once) and the 'observer effect'. In turn, this raises philosophical considerations about the nature of reality itself and uncovers notions of interconnectedness, wholeness and infinity, all of which are addressed through the art practice.

Many theories have been developed based on the numerous different interpretations of the results of these experiments and this research draws on the ideas of two scientists who thought deeply about the implications of the bizarre nature of the quantum realm. Firstly, the Nobel laureate, Niels Bohr (one of the Copenhagen founders of quantum theory) whose theories are discussed in *Chapter 6: Patterns of Entanglement—Diffraction and Moiré* which includes questions of quantum entanglement and also discusses Karen Barad's development of Bohr's theories into their theories of agential realism and diffractive methodology. [Note: Karen Barad uses the gender pronouns they, them, their, theirs.] The quantum questions are physically expressed through the materials (diffraction grating) and ideas entwined in the material investigations and artworks for this enquiry. Moiré, an interference effect, is explored in this research and Olafur Eliasson (one of the few artists to feature moiré) is discussed.

Theoretical physicist David Bohm sought to reconcile Bohr and Einstein's opposing views and the third chapter in this part, *Chapter 7: Unfolding from the Enfolded—David Bohm's Implicate Order,* discusses Bohm's unorthodox theories and outlines examples of the response of several artists to them. Bohm examined space, time, matter and light and his theories are extensive; those of the implicate/explicate orders are particularly compelling. In his seminal book, *Wholeness and the Implicate Order* (1980), he describes how the apparently separate aspects of the phenomenal world originate from a hidden order of a non-local interconnectedness that links an underlying undivided wholeness with what he called "the universal flux" (1980:52-3), a state where everything is in a process of becoming and can only be known implicitly.

As Bohm's theories propose an underlying wholeness and interconnectedness to reality, they serve as a significant inspiration for this research and many of the artworks pay homage to them directly. The metaphors Bohm uses to describe them provide rich inspiration for the artistic investigations; for example, he engaged textile metaphors of 'folding' to express and concretise his theories about the more profound nature and processes of reality. An enfolded, implicate order unfolds the explicate order through a process he named the *holomovement*. In response, this research explores the notion of folding in different ways, both phenomenologically and metaphorically—not only by physically pleating materials but also by applying ideas of unfolding to the unlikely realms of light and space by using optical materials such as mirrors and prisms.

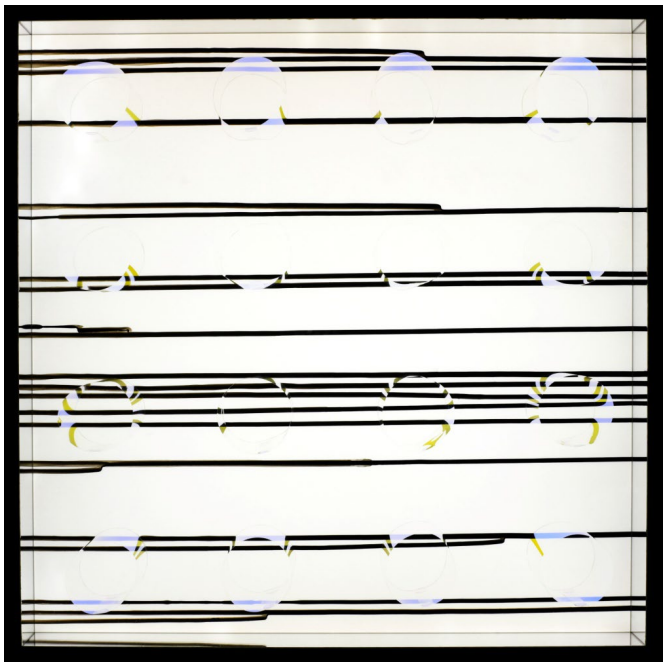

Image 8: *Quantum Questions—Line Interrupted #3*. LED light, dichroic film, calligraphy ink, drafting film, mirror, frame. 2017.

Part IV—Making Material discusses the contribution the art practice makes to this research. Further to the insights gained from the investigation of the science of light, the main body of this research has been achieved through an artistic exploration and analysis of materials followed by the creation of several series of resolved artworks which include photographs, lenticular photographs, mixed-media works, digital films and installations. The employment of each medium requires its own approach to working and re-working the themes and motifs. The artworks not only represent and illuminate the bizarre, ehermeral properties of quantum light but also visually and experientially demonstrate them to the viewers.

Part IV has three chapters, each considering the practice from a different angle. Firstly, *Chapter 8—Material Investigations,* discusses the value and process of thinking through materials followed by an examination of specific materials, notably prisms, mirrors, dichroic materials and diffraction grating. An in-depth interrogation of the optical qualities and discussion of two of the materials (prisms and diffraction grating) precedes a less detailed account of the exploration of two other materials, half-silvered mirror and dichroic film. The investigations led to the discovery the illusory qualities of all these materials and their potentiality to express the ephemeral quantum themes, such as unifying dualities, superposition and the entangled relationship between subject and object.

In *Chapter 9: Process—Lenticular Series,* the several lenticular series are treated as a case study to demonstrate the evolution of the artistic process (which is complex and entangled). In particular, there is a detailed account of the development of how the properties and use of this media entwine with the key theme of unifying dualities. The physical and optical qualities of lenticular photography are interrogated and the technical possibilities of lenticular production were developed and pushed beyond the usual limits of the process. This generated novel outcomes that contributed to illumination and expression of the themes of unifying dualities and Bohm's holomovement.

The third chapter in this part, *Chapter 10: Resolved Outcomes,* discusses how the art functions as an apparatus that reveals something that is usually hidden and how the artworks embody and visually supplement the arguments and themes beyond simply illustrating them. The artworks convey the products of the research experientially to non-academic audiences as their compositions focus and direct the viewers' attention. The Reticular Activating System (see Chapter 3) allows the viewer to form their own perceptual links.

As it is not possible to discuss all the thirty-plus series of artworks created during this project, four resolved artworks were selected for analysis in this section. Reflection on

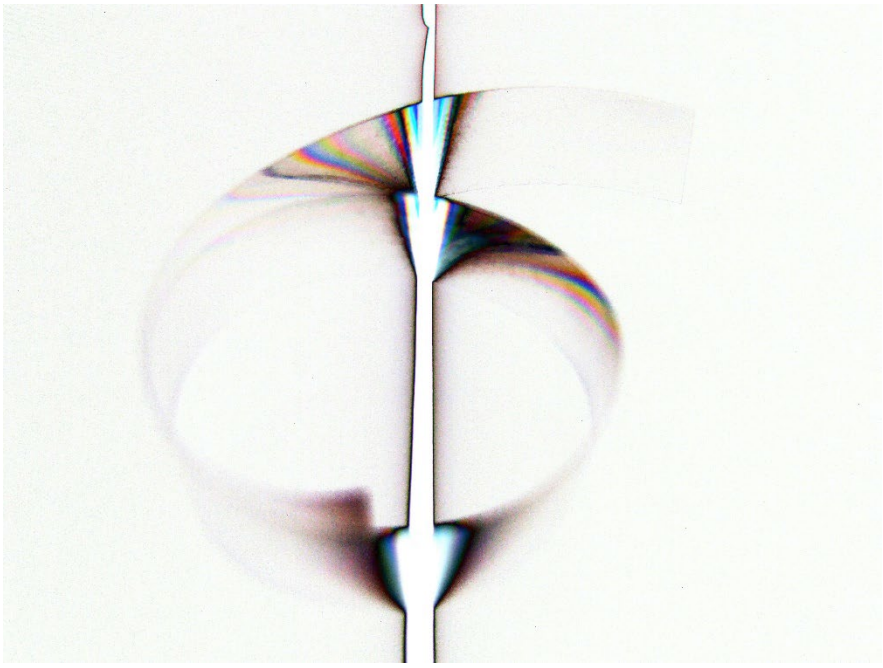

Image 9: Diffraction grating, LED light, black paper, Photoshop manipulation. 2018.

these works resulted in unpicking and examining what exactly resided within them and the discussion of each focuses on specific aspects, such as the artistic devices and processes used and how the use of the materials expressed and interrogated some or all of the themes that thread throughout the research, including:

- Highlighting the underlying oneness and interconnectedness of all things
- Representing the paradox of unity from multiplicity
- Beyond dualities—exploring the notion that dualities can be unified
- Expressing and revealing the hidden, immaterial aspects of our reality
- Questioning boundaries

The capacity for some artworks to successfully demonstrate (more than represent or illuminate) quantrum properties, such as, superposition and quantum entanglement is discussed.

This chapter concludes with a description of the final exhibition, *Quantum Light—Beyond a Crisis of Perception,* which includes resolved artworks and immersive installations.

Photo Essay

A photographic dataset was gathered to record the interrogation of the properties of the materials. Although photographs cannot fully convey the phenomenological experience of the investigations, they serve to evidence the practice. They provide a non-verbal contribution to knowledge that extends the range of sensory and affective responses to the elusive subjects of enquiry, aggregating to create an overarching oeuvre that holds and represents these themes. Many photographs from this dataset accompany the text of this thesis as a companion photo essay which visually supports and extends the text providing an additional form of information (independent from but related to it). Together, the two threads of different kinds of information presented side-by-side offer a dual experience of the subject matter. The images address spatial, sensory and intuitive modes of thought while the text addresses linear thinking and language, integrating linear thought with holistic thinking, language with spatial thinking and rational thought and intuition.

The photo essay is an intermediary between the thesis text and the studio practice and is a third factor in disseminating the information and discoveries gathered in this research. The images go beyond illustrating the text, they are both a record and part of the studio practice. However, they also exemplify the text, thereby serving both analytical and

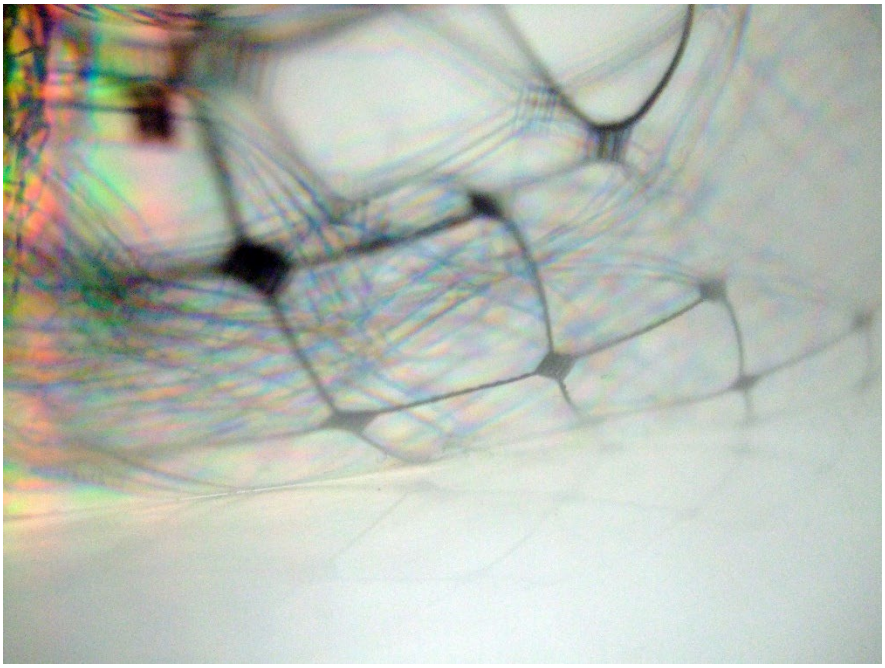

Image 10: Diffraction grating, birdcage netting, LED light. 2018.

evocative ways of thinking (Rose 2016:340-345). The relationship between specific images and accompanying text varies. At times, the photographs serve to illustrate ideas discussed in the text so that the text and images are making the same argument; however, at other times, there may be no direct crossover between the image and the content of the adjacent text. The non-linear and evocative nature of the visual information provides the reader with the opportunity for free association, making their own individual links and inferences. Through a whole brain experience, the reader becomes both a reader and a viewer simultaneously—both/and.

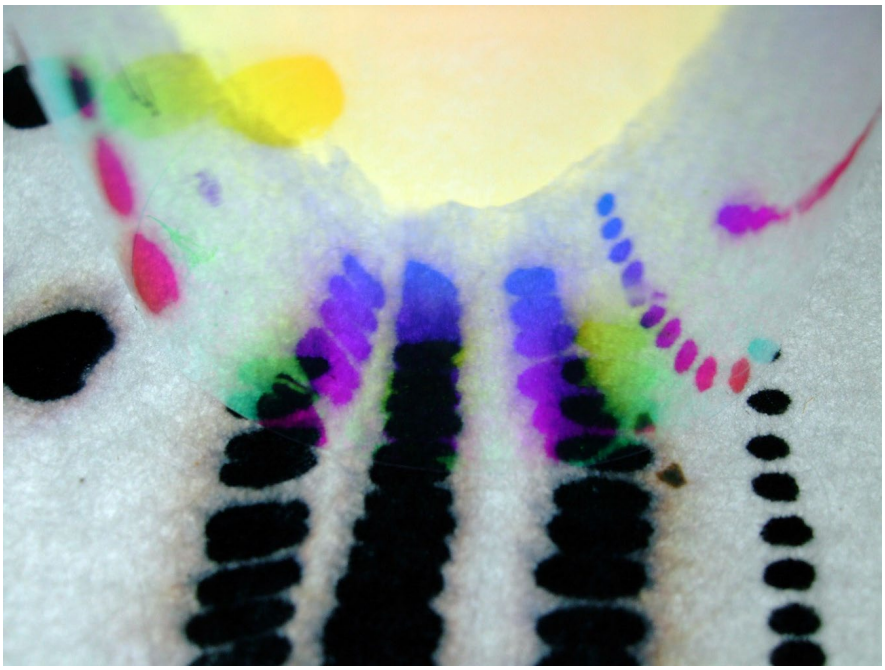

Image 11: Black ink drawing, dichroic film, LED light. 2018.

Part I—Artists in Context

Chapter 1
Edges of Becoming—Art Inspiration

Introduction

The *TRA: Edge of Becoming* exhibition was held at the Fortuny Museum during the Venice Biennale in 2011 and provided the initial inspiration for this research. It showed more than three hundred works by over eighty artists under the themes and concepts packed within the exhibition's title (selected works are discussed below). The art was presented as a pilgrimage and the curators aimed to create an aesthetic, intellectual and enlightening experience. It was a powerful and profound encounter. In viewing the art on show, I felt a strong but curiously indefinable sense that I had experienced something of the intangible mysteries at the edges of becoming—the hidden fabric of the universe. This awareness was elusive, invisible and hard to describe as it was felt rather than quantified. Just as Japanese graphic designer and curator, Kenya Hara, writes that all the other senses take place through touch (2007:100), the curator of the exhibition, Axel Vervoordt, suggested that we use "our eyes to feel the unseen" (2011:8), enabling us to experience something that is usually beyond our sensory perception.

The artists, such as Heinz Mack, Lygia Pape and Massimo Bartolini, had rendered ethereal, immaterial qualities into material form in many different ways, many using light itself. In the first instance, this research was a personal response to TRA, leading to a desire to probe deeply the intangible, hidden order underlying all things that the works alluded to by applying the level of attention and commitment an art practice-based PhD demands.

The exhibition catalogue essays are cross-disciplinary and include insights drawn from scientific and Eastern philosophical worldviews to provide a more complete picture of the hidden mysteries beyond everyday experience. It pointed to the first steps for this research and approaching the project from an interdisciplinary position opened up the themes and lines of investigation that weave throughout. The essay, 'Nothingness' (2011:47-59) by physicist, Eddi De Wolf (a researcher at CERN and professor at the University of Antwerp), was of particular value because he interlaced art, Eastern mysticism, Western philosophy and physics.

Two threads of enquiry became particularly relevant: firstly, Eastern thought and secondly, quantum physics. Eastern thinking and quantum physics have many corresponding views on questions of materiality and immateriality. However, quantum physics undertakes to

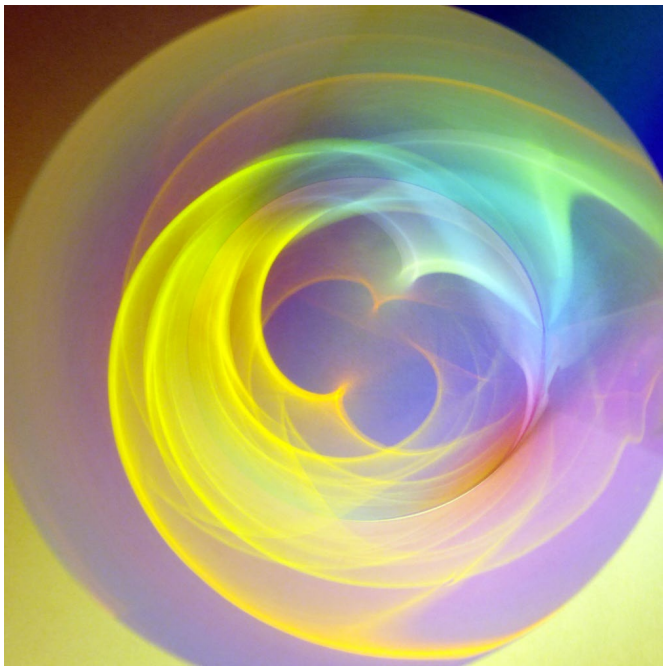

Image 12: From *Ensō* series. Dichroic film, sunlight. 2018.

quantify phenomena, thereby offering a more grounded and materially based explanation of the edges of becoming than the qualitative perspectives of Eastern metaphysics. Nonetheless, although the history of physics has been founded on materiality, it has been problematised by quantum discoveries which transcend the phenomenal world. For example, theories of particles and antiparticles describe how 'virtual' subatomic particles flicker in and out of being—a threshold at the edge of becoming that has now been measured (De Wolf 2011:56).

Drawing on both scientific findings and an Eastern perspective disrupts the habits of Western thinking; both are equally mysterious, baffling and paradoxical. A review of the correspondences between the two is discussed below following an account highlighting relevant viewpoints on the edge of becoming drawn from Eastern thinking, including the *Tao Te Ching* and Buddhism.

To further understand and clarify the prevailing attitudes to the material/immaterial interplay in the East, I made a research trip to South Korea and Japan. It was inspired by frequent references to Eastern thinking in the catalogue essays, Lee Ufan's work in *TRA: Edge of Becoming* and a concurrent exhibition in Venice of the South Korean *Dansaekhwa* (Monochrome) Group. Ufan (see below) is one of the most prominent exponents of Dansaekhwa which pays particular attention to the properties of objects and materials. It became clear that employing materials primarily for their material properties could successfully serve to portray and advance understanding of the immaterial, and implementing the material investigations that form the dataset that underpins the art practice was a direct result of this. As an example of how Eastern art influenced the creation of the works for this enquiry, the exploratory *Ensō* series is described below.

Edge of Becoming—Ensō Series

In Japanese Zen calligraphy, ensō symbolises the universe and *mu* (the void). It is the practice of drawing a circle, a universal symbol of wholeness, with a single brushstroke to represent enlightenment, truth, the entirety of the universe and equality. The *Ensō* series created for the current research explores the notion of the void as being pregnant with possibility and reveals a complexity of colours created by the wholeness of white light meeting a circle of dichroic material. The resulting ensō-like images, although abstract, are emotive. They combine the simplicity of a circle with the dynamic, complex forms manifested by the reflected light rays—forms that are, in effect, 'drawn by light'. The production method is simple, however, the outcomes are more complex—they are created by photographically capturing the dance of sunlight shining through a circle of dichroic

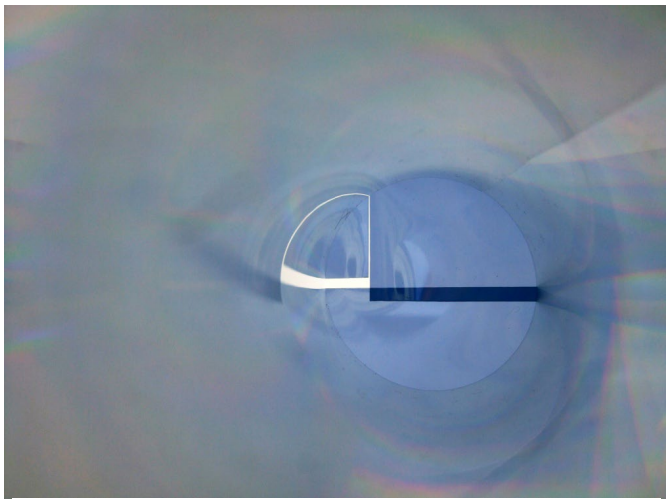

Image 13: Cut black paper, diffraction grating, LED light. 2018.

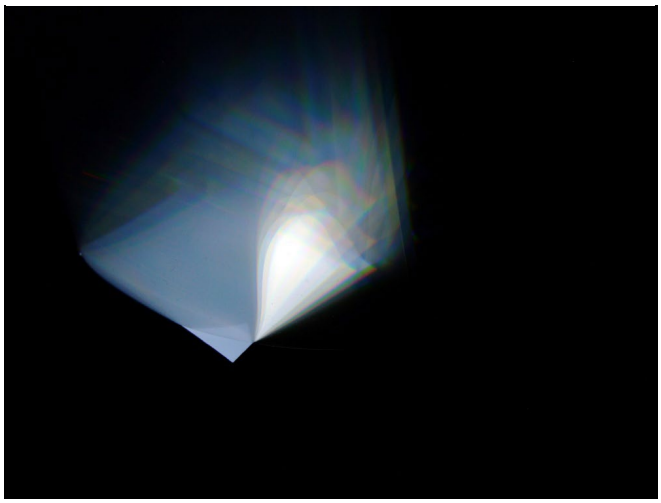

Image 14: Cut black paper, diffraction grating, LED light. 2018.

film. The dance of light and colour produces the potential for countless photographic images, each created by simply shifting the camera position.

Exhibition—*TRA: Edge of Becoming*

The initial response to the exhibition was to contemplate, explore and articulate the many intangible, hard questions and 'big' themes the exhibition raised, for example, looking to "the void as the pregnant possibility of energy, to chaos as the state of infinite becoming, and to becoming as the movement towards a situation" (Fortuny 2011). These themes were encapsulated in the title, *TRA: Edge of Becoming*. Vervoordt explained that 'tra' is often used as a prefix or suffix representing the in-between, thresholds and boundaries and connects to the Japanese notion of *ma*, indicaing that empty, negative space between two objects is just as important as the positive space of an object. Furthermore, he pointed out that the subtitle *Edge of Becoming* was "chosen to bring us closer to discovering the interconnectedness with a more universal sense of experience" (2011:3).

Following from this and in response to quantum theories on light and Eastern thought, in-betweens, edges, interfaces and thresholds of becoming are effective bridges between binary oppositions, such as interior/exterior, invisible/visible, dark/light and subject/object and provide a rich resource. Additionally, throughout this research, questions of both boundaries and unifying binary oppositions are recurring themes and are woven into the practical investigations and resolved artworks themselves.

***TRA: Edge of Becoming*—Selected Works**

One of the works in the show was *Red Shift*, a 'ganzfeld' work by Californian Light and Space artist, James Turrell (1995), where space, surface, colour and light are perceived as a single, homogeneous substance, offering both an experience of the edge of becoming and a felt sense of the void (Turrell is discussed in Chapter 2). This work was complemented by Anish Kapoor's *Portrait of Light Picture of Space* (1993), a two-metre high, blood-coloured, free-standing wooden rectangle, bounding an empty space creating a void that is both framed and open at the same time. Here, just as in many of his works, emptiness is used to capture and express the unfathomable. Kapoor, who has been a Buddhist for nearly 30 years, repeatedly explores the void, for example, in his *White Dark* series, where the shapes of pure white circular forms are defined by the shadows created by the ambient light. Paradoxically, Kapoor creates the space of the voids through his use of the material rather than by material absence. Moreover, the representation of the void in the *White Darks* permits a unification of dualities. He explains that he makes an object that is not an object by making a hole in the space, a piece of void that unifies dualities,

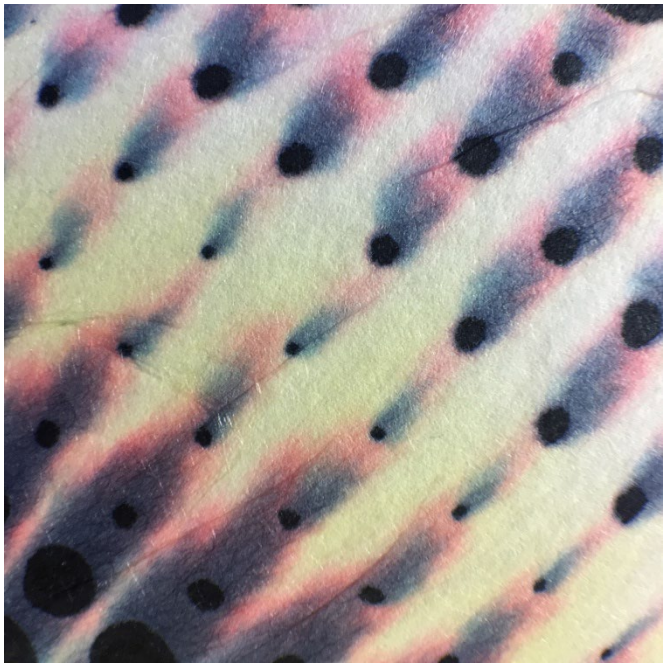

Image 15: Black ink on Japanese Shoji paper. 2017.

> at once finite and infinite…inside and outside, earth and heaven, male and female, active and passive, conceptual and physical, thus renewing the process of knowing (Kapoor 2017:369).

Lee Ufan was another artist in the exhibition with Buddhist influences. He was one of the major theorists and practical proponents of the avant-garde Mono-ha (Object School) group of Japanese and Korean artists, and he expressed his viewpoint early in his career in an article, 'Beyond Being and Nothingness: A Thesis on Sekine Nobuo' (Tate s.d.) which may be the origin of Mono-ha. His influences transcended both Eastern and Western thinking as he was also influenced by the phenomenology of Martin Heidegger and Maurice Merleau-Ponty together with the writings of Michel Foucault (Monroe, 2011).

Ufan is concerned with aspects of being, infinity and emptiness and how he can portray these ideas in his art. He explains, "Space means the infinite…Buddhism teaches that being is possible only because there is also nothingness, and appearance coexists with disappearance" (cited in Munroe 2011:30). He refers to his painting process as the art of emptiness or *yohaku* (often translated as 'margin' referring to the unpainted area in classical Chinese, Korean and Japanese art—the characters in *yohaku* signify 'remainder' and 'white', implying a void (Teo 2015)). His placement of objects and mark-making emphasises the interrelationships between space and matter. His work not only addresses questions of infinity, the dualities of doing and non-doing and occupied and empty space, but also focuses on the perceptions of the qualities of materials and their relationships. Ufan has a typical Eastern appreciation for materials and his abstract approach engages with the materiality of the materials and media he uses.

Dansaekhwa

Ufan is also part of the South Korean Dansaekhwa movement. Like other Dansaekhwa artists, Ufan focuses on a meditative aspect of art production which is characterised by the relationship between, firstly, the materials themselves, secondly, the materials and the artist and thirdly, the artwork and viewer. Although there are similarities, Dansaekhwa is often compared to Western monochrome and Minimal art's rationality and logic; however, the difference is the approach which is holistic and meditative in nature. Ufan and other members of Dansaekhwa were inspired by Western Modernism but also sought to connect to their cultural and spiritual roots, including Taoism, Confucianism and Buddhism. Unlike Western minimalism, their style is not one of reduction, but rather of incremental accumulation and layering, and, notably here, an exploration of the physical qualities of materials and their ability to interact with the viewer. These factors were key to the approach to materials and processes of art production for this research which aligns

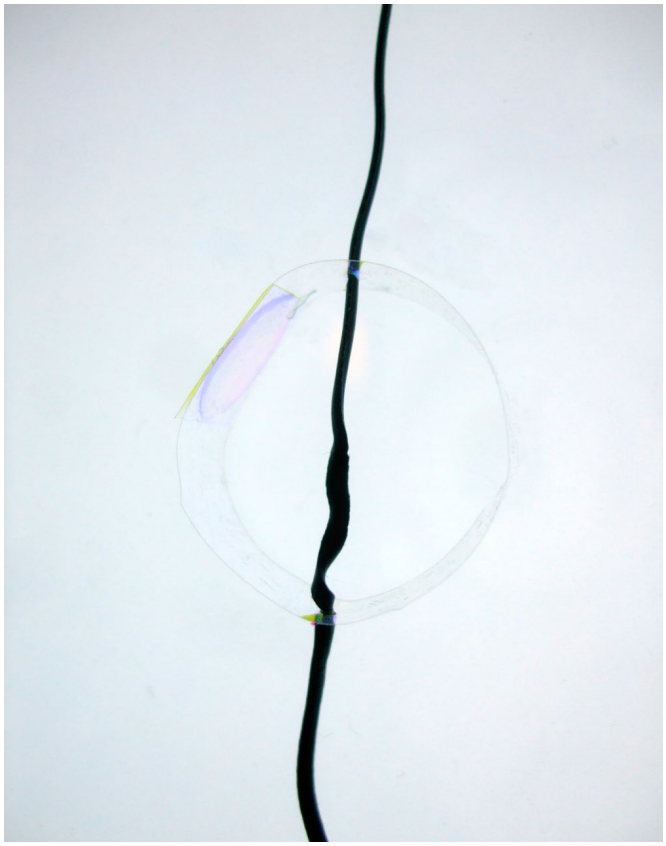

Image 16: Dichroic film, wire, glue dot, LED light. 2021.

with the methods used by Dansaekhwa artists through layering and repetition of mark-making and motifs.

South Korean contemporary art, much of which is abstract, also focuses on material qualities and process. For example, in an exhibition from the permanent collection of the National Museum of Modern and Contemporary Art (MMCA) in Gwacheon, *Part I: STOP, and SEE* (2015), two particularly relevant sections resonated with the themes of the current research, firstly, *See the Invisible* and, secondly *See the Boundary.* In another exhibition in the same museum, *The Sound of Things: Materiality in Contemporary Korean Art*, was a selection of contemporary South Korean works explicitly "based on the thematic criteria of the element of time in the becoming of things" (MMCA Gwacheon 2015). Using the very nature of the material qualities to depict the immaterial, the works on display revealed "what is more-than-materiality" (MMCA Gwacheon 2015). In response to this, the aim of this research was to interrogate the nature of the materials (in particular, the optical materials) to promote fresh discoveries of the properties which would enable ways to be found to present and bring to form things that are usually difficult to perceive.

Edge of Becoming—Eastern Philosophy

A key aim of this research is to bridge or disrupt dualities. Eastern thinking uses paradoxical connections of dual opposites to point to the unfathomable and the whole (in Western thinking there is a tendency for dualities to be used to oppose and separate). For example, the Eastern systems of knowledge "have always sustained the dynamic processes of non-linear interaction between Yin and Yang polarities" (Fortuny 2011). Originating in China and fundamentally embedded in the Eastern worldview, yin and yang is a concept of duality forming a whole where seemingly opposite or contrary forces govern the universe—they are, however, in essence, complementary, interconnected and interdependent. The yin/yang symbol, *Taijitu*, shows that the one gives rise to the other—represented by the small dots in each half of the symbol, each carries the seed of the other. The artworks of the Lenticular series exemplify this independence of opposites see in Chapter 9.

Lao Tzu's ancient and enduring text, *Tao Te Ching,* is laced with paradoxical complementary opposites which are seen as interdependent entities that dynamically change towards their opposites to describe the unfathomable. For example, there is an interdependence where substance and material existence springs from non-existence (*Tao Te Ching*, Chapter 40) and being and non-being generate each other (*Tao Te Ching*, Chapter 2). A similar use of paradox inhabits Buddhism; for example, *The Heart Sutra* (which contains the essence of Buddhism) declares,

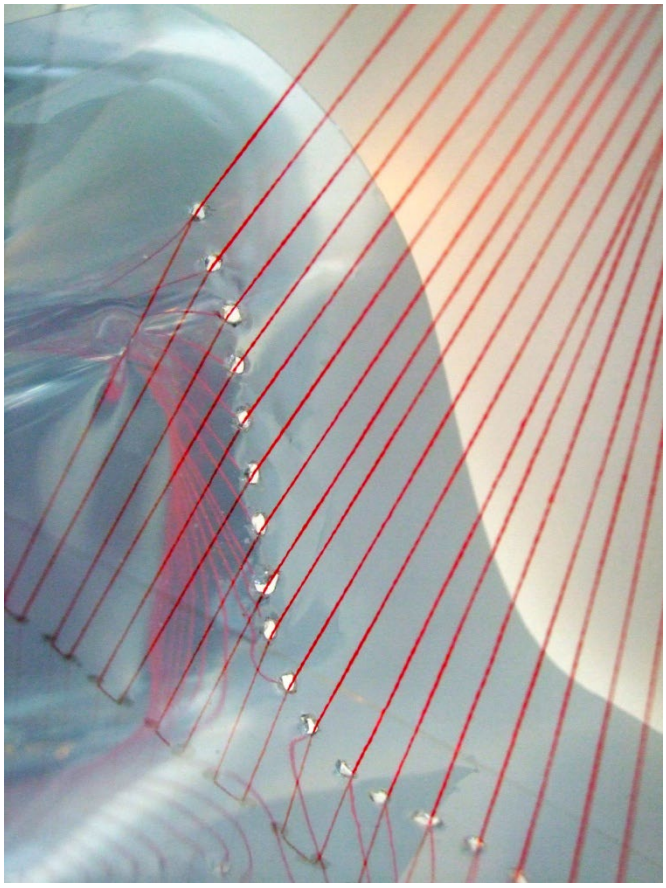

Image 17: Mirror with drilled holes, two-way mirror film, red thread. 2018.

> form is emptiness, emptiness is form;
> emptiness is not separate from form,
> form is not separate from emptiness;
> whatever is form is emptiness,
> whatever is emptiness is form (Translation: Red Pine 2004:2).

Correspondences between Quantum Physics and Eastern Philosophy

As in Buddhism, emptiness is at the heart of new physics—every atom is almost entirely empty. Shantena Sabbadini (a quantum physicist who worked on the quantum measurement problem and black holes and has also written on the *I Ching* and the *Tao Te Ching*) identifies notions of complementary opposites and the 'essential' void at the heart of existence among the corresponding themes. He explains that in quantum physics the vacuum, the zero energy state, is a very active emptiness and is not an inert absence of energy or matter; rather, "it contains infinite energy, and paradoxically physicists have to subtract this infinity out of their calculations in order to get results that make some sense" (2013:67). Ordinarily, emptiness signifies the void or nothing; however, it contains pure potential and speaks of infinity. In the words of Karen Barad, "Nothingness is not absence, but the infinite plenitude of openness" (2012:16).

The Tao is often translated as 'the Way' or 'the Path' and is the Taoist principle of change and becoming. The physical universe we call reality—David Bohm's explicate order—correlates to Lao Tzu's '10,000 things' (Sabbadini 2013). Sabbadini brings concepts from quantum physics to bear in his translation and commentary of this ancient text and draws many correspondences between the Tao and quantum physics in both *Pilgrimages to Emptiness* (2017:227-247) and his translation of the *Tao Te Ching* (2013:16-21). On the correspondences between physics and the *Tao Te Ching*, he observes,

> Funnily enough, the language of this ancient text seems more adequate than our contemporary scientific-technical language to comprehend the strange reality quantum physics shows us (2013:21).

Being and Becoming—From a Scientific Perspective

Sabbadini devotes a chapter in *Pilgrimages to Emptiness* to being and becoming (2017:135-164) which he relates to time. Beyond this, through a scientific lens, the edge of becoming is reflected in the title of Nobel laureate, Ilya Prigogine's book, *From Being to Becoming: Time and Complexity in the Physical Sciences* (1980). His theory of dissipative structures (structures that appear to develop order out of chaos) won him the Nobel Prize in 1977. A scientist interested in the interface between classical and quantum mechanics and a signatory of the Humanist Manifesto, he took a different view from other scientists on questions of being and becoming. Aiming to move beyond the classical (Newtonian)

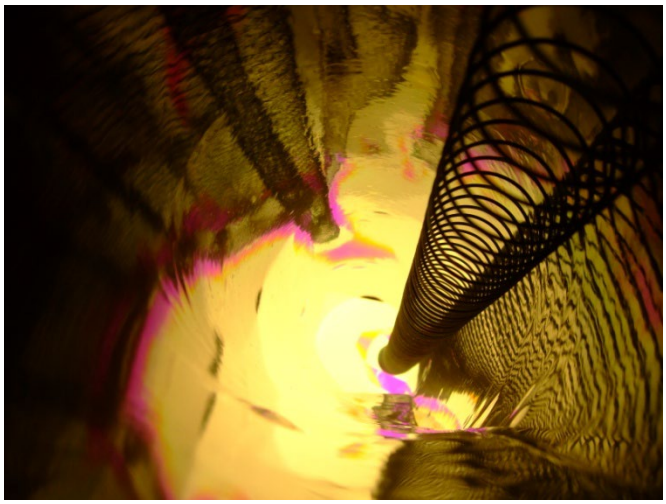

Image 18: Two-way mirror film, coiled spring, diffraction grating, sunlight. 2016.

view where being was seen as the same as becoming, he equated the relationship between being and becoming as the relationship between complexity (the role of chaos) and the basic laws of nature. Contrary to other scientists, like Einstein and Bohr, he saw becoming as the primary element and an expression of the instability of the universe. However, Prigogine employs the unity of dualities in recognising that,

> [I]n order to express this [becoming], we also need elements that are permanent. We cannot have becoming without being, just as we cannot have light without darkness or music without silence (2004).

Basil Hiley, a quantum physicist who collaborated with David Bohm, distinguishes being and becoming in the following way—with being, we remain the same; however, becoming is a process and the objects of the world of classical physics emerge from this process. He goes on to say, "Thought is about becoming and not being. Being is a relative invariant of an overall process of becoming" (2020). Referring to Bohm's theories of the implicate/explicate orders (see Chapter 7), he adds that becoming is a complicated process of movement, a folding and unfolding.

The Dalai Lama, who considered David Bohm to be his physics teacher (Peat 2016), observes that although the Buddhist view of reality emerges through an inner mode of enquiry, it nonetheless has surprising correspondences with the findings of quantum physics and cosmology, modes of knowledge deduced by observing the outer world. He recognises the value of cross-disciplinary exchange and since 1983 he has been regularly engaged in collaborative conversations that bring together physicists, cosmologists, neuroscientists and Buddhist scholars and monks. The dialogues are aimed at shedding light on life's great questions and the nature of reality by exploring the commonalities and differences in worldviews. Recent dialogues are recorded in *The Monastery and the Microscope: Conversations with the Dalai Lama on Mind, Mindfulness, and the Nature of Reality* (Hasenkamp 2017).

Fritjof Capra also saw strong parallels between Hinduism, Buddhism, Taoism and modern physics (especially quantum mechanics), which he documents in *The Tao of Physics* (2000). His explorations were followed by others like Paul Davies, Irvin Laszlo and Gary Zukov. However, some, like Victor Stenger, author of *The Unconscious Quantum* (1995), felt that these correspondences were devalued by being hijacked by the New Age movement.

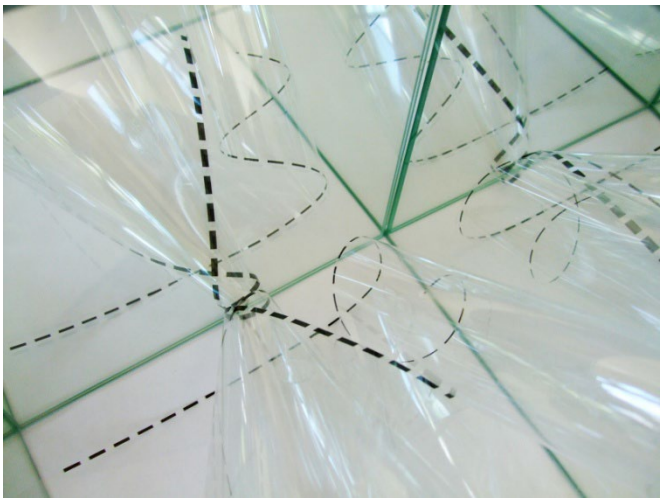

Image 19: Mirrors, printed acetate. 2015.

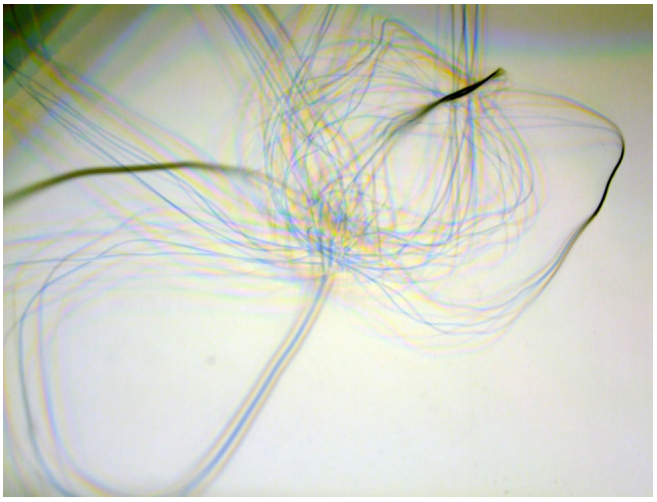

Image 20: Wire, diffraction grating, LED light. 2016.

Being and Becoming—Western Philosophy

The dichotomy of being and becoming has concerned philosophers throughout history, from Heraclitus, Parmenides, Plato and Aristotle to Heidegger and Deleuze. Around 500 B.C. Heraclitus proposed that all things are becoming, that is, all are changing and impermanent. Later, Parmenides opposed this by affirming the opposite—the reality of permanence. Later still, in the first section of his *Timeaus*, Plato distinguished between the two aspects of reality, *being, "*that which always is and never becomes" and *becoming*, "that which always becomes and never is" (cited in Jowett 2012). Plato saw the world of becoming as the constantly changing physical world perceived through our senses. He viewed being as the unchanging abstract phenomena that cause the essential nature of things we perceive in the world of becoming.

Later, for Gilles Deleuze and co-author Felix Guattari, 'becoming' is a fundamental concept that is neither an attribute of, nor an intermediary between, events, but is a characteristic of the very production of events (Stagoll 2010:25). In *A Thousand Plateaux,* Deleuze and Guattari explain that becoming is an 'in-between' condition, describing this in terms of a line:

> A line of becoming is not defined by points that it connects, or by points that compose it; on the contrary, it passes *between* points...A line of becoming has only a middle...A becoming is always in the middle; one can only get it by the middle. A becoming is neither one nor two, nor the relation of the two; it is the in-between, the border or line of flight or descent running perpendicular to both (2013:341-342).

The ideas in this quote are expressed in the animated film *Edge of Becoming I: Red Thread* (described below). In this research, the 'edge of becoming' denotes the interface between the material and the immaterial—it touches on, but does not engage in, the longstanding philosophical debates on definitions of being and becoming. Rather, there is a focus on what revelations looking through a scientific lens might uncover. Many have sought a universal key to the themes around the edge of becoming. For example, physicists have been chasing a 'theory of everything' for the last century. By its nature it may never be complete, nonetheless, this research illuminates and draws links between modes of understanding through an inclusive, syncretic and non-linear approach that spans disciplines. Highlighting the intersections between very diverse worldviews with different frames of reference and looking at the shared insights from these multiple vantage points simultaneously has enabled a fuller understanding of the mysteries at the edges of reality. However, no one single position can reveal the whole truth, though each of these perspectives, like coloured threads in a tapestry, can provide illuminating facets that point to the whole, contributing to an interwoven but open body of knowledge. It is

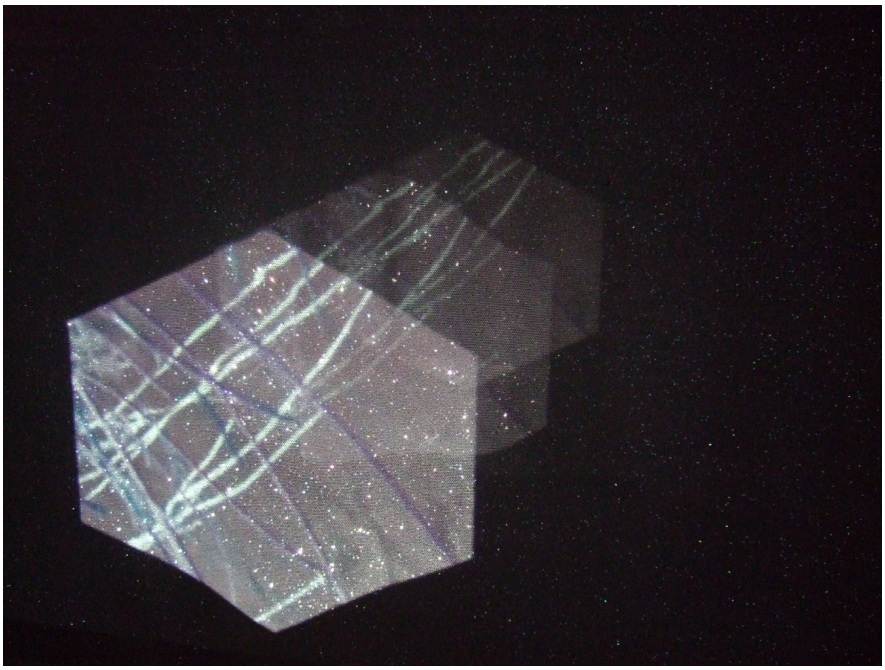

Image 21: Mapped projection of digital film onto three layers of sparkle fabric. 2016.

within this context that the artworks were created for this enquiry—they contribute new forms through

a visual and experiential language by weaving a few more stitches into the rich tapestry of existing knowledge.

Textile Notion #2: Tapestry

Tapestries are metaphors for interconnectivity—smaller parts, threads, are woven together to form a whole. The meaning is revealed by seeing the different parts together. One part makes little sense without the others. They are woven on a loom threaded with vertical warp threads. A multitude of horizontal weft threads are woven through the warp to create part of the overall pattern, design or iconography which can be symbolic, representational or abstract. Tapestries are usually weft-faced (the weft threads completely hiding the supporting warp). The wefts can be of several diverse materials which become blended, nonetheless, they still remain distinct when woven.

In his 1979 Nobel Prize Lecture, *Towards a Unified Theory: Threads in a tapestry*, American theoretical physicist, Sheldon Lee Glashow compared tapestries with particle physics, saying,

> Tapestries are made by many artisans working together. The contributions of separate workers cannot be discerned in the completed work, and the loose and false threads have been covered over. So it is in our picture of particle physics (1979).

Practice—Edge of Becoming—Digital Animation Series

Although the themes of 'the edge of becoming' are difficult to pin down, the *Edge of Becoming* series comprising several short digital animation films was created to explore this theme using moving image (two are described below). The films coherently embed and express a multitude of ideas simultaneously, both visually and experientially. The animated imagery is generated through algorithms embedded in the software and the resulting films exist as digital information, only crossing the interface into physicality (traversing the virtual and the real) when played on a screen. They explore unfolding/enfolding as the *process* at the edge of becoming, referencing Bohm's theories of the implicate/explicate dance (see Chapter 7) with passing reference to Serres' and Deleuze and Guattari's writings on emergence, and each film is an abstract, impressionistic imagining of this enfolding/unfolding at the interface between the

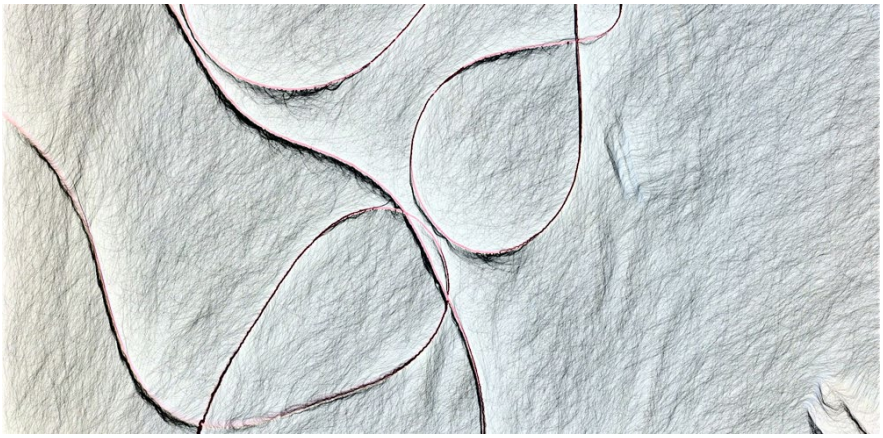

Image 22: ***Edge of Becoming I: Red Thread*** **Film still. 2015.**

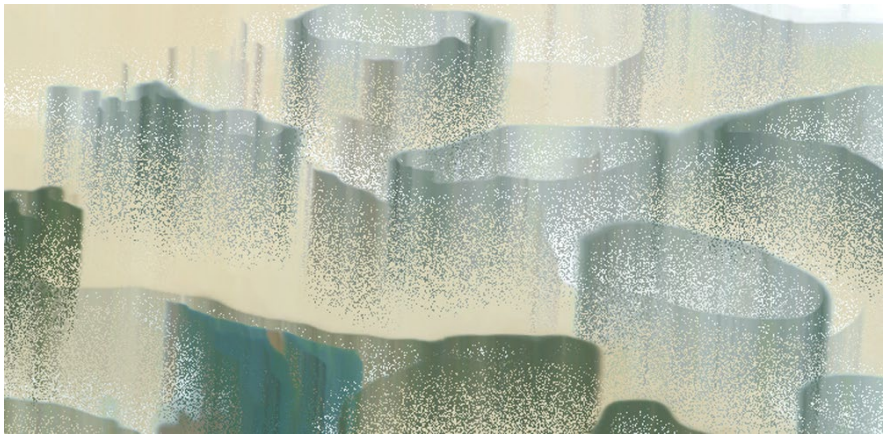

Image 23: ***Edge of Becoming II: Particle/Wave.*** **Film still. 2015.**

underlying interconnected field of existence and manifest phenomena. Each explores the elusive seams between matter and the immaterial, the crease where things differentiate. The liquidity of the moving image integrates the dimension of time into the work and the moving image articulates a space-time-matter threshold—Karen Barad (see Chapter 6) coined the term "spacetimemattering", fusing the words to expose their entanglements (2010, 2014) and referencing the elements of Moholy Nagy's original question.

Although not obviously so, the imagery in these two films is drawn from roots in textile practice. In *Edge of Becoming II: Particle/Wave,* abstract, rippling tubular shapes create organza-like folds that dissolve and reform, shifting into and out of being. There is a dance between transparency and opacity as dynamic, undulating waves move from right to left across the screen. Translucency sits on a continuum between transparency and opacity, bearing properties of both. Wave/particle duality is referenced—the crests of the moving forms are the surface edges of the waves which are distinct and delineated, contrasting with the depths below, dissolving shafts made up of granulated, dissipating particles. At times, a spreading blackness envelops the screen; however, the waves are persistent and emerge anew through remnants of the blackness lingering within the wave as grainy particles. The tubular shapes (a form that reappears in other artworks) indicate translucent, vasiform folds that dissolve and reform, shifting in and out of being, like cloth that lays flat in two dimensions but can be folded to create three-dimensional shapes, thus, creating a dynamic between inside and outside, form and emptiness.

Textile references are more evident in the other film, *Edge of Becoming I: Red Thread*. The textile-inspired motif, a looped red thread, unfolds from a field of shifting black fibres that emerge from a dynamic white void. The movement of this red strand articulates changing relationships and interconnections, with both the black filaments that ride on rippling waves generated in the underpinning white ground and with itself. The motif of the red thread is revisited and reworked in other artworks in this research; for example, a mesh of red threads is printed on the surface of the acrylic blocks of *Indeterminate Interfaces #2*. In her essay, 'The Re(a)d Thread', Lesley Millar discusses the power and metaphor of the red thread in textile art, film, cloth and clothing. She states,

> Used as a device within textiles, the red thread becomes an intervention within the construction or upon the surface, one which activates our interest, becoming the read thread, sign-pointing the narrative within the cloth (2014:33).

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Initially, this PhD involved moving from the inspiration of the nebulous qualities of the works shown in the *TRA: Edge of Becoming* exhibition towards a deeper understanding of

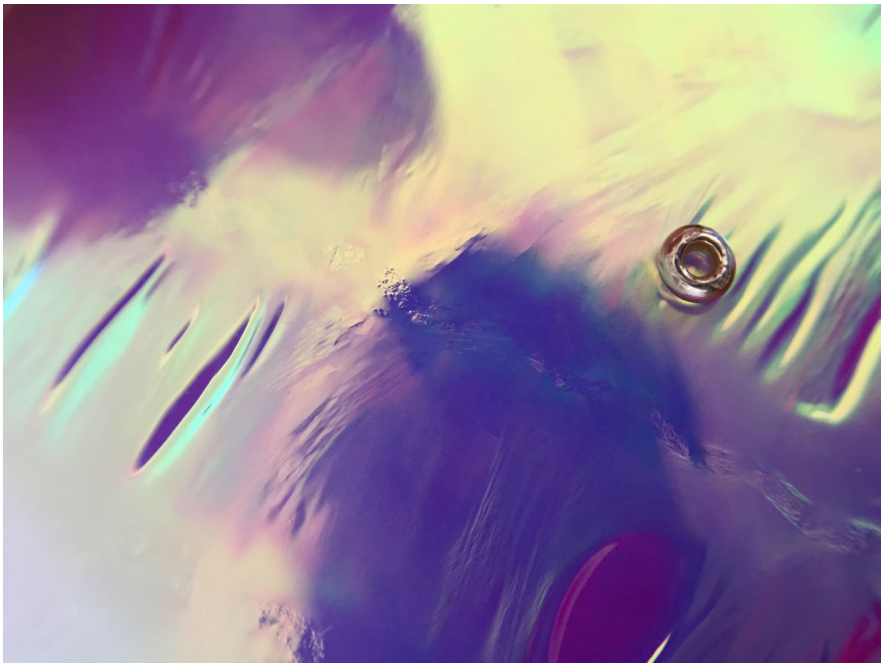

Image 24: Gold bead, embossed dichroic film. 2016.

the mysteries behind reality. The exhibition was a formative experience that provided a model for the starting point for this research and paved the way for the possibility of rendering immaterial qualities to material form which could then be transmitted to others. An artist can hold widely differing perspectives simultaneously and synthesise forms, images and motifs to create a visual language that others can access.

Taking the lead from the curatorial approach to *TRA: Edge of Becoming* led to both centring this research on an investigation of the quantum view of light and employing a cross-disciplinary approach. By observing correspondences between Eastern philosophy and quantum physics, several themes emerged which included paradoxical questions of materiality and immateriality, such as the void (an emptiness pregnant with potential energy), unifying dualities and an underlying interconnected wholeness.

In the following chapters it will be shown how these themes evolved and multiplied as the research progressed, centring on quantum physics which, applied to this research, derives from a study of light which poses questions of wave/particle duality (this applies to all matter, not just light). The initial focus of the project concerned the material and immaterial; however, light became the primary focus for the themes and artworks. Even though the things we experience appear to be separate, the aim of this enquiry was to move beyond dualistic thinking (separation of mind and matter, science and spirit, subject and object), towards an expression of an interconnected wholeness that underlies everything we experience. The themes that emerged are elusive, difficult and multi-faceted and required a methodology that could manage and concretise the many strands—textile thinking has provided many keys to unravelling and interweaving them (see Chapter 4).

Many of the artists who addressed these themes in the exhibition had East/West influences. One example, Lee Ufan, was discussed above. Much of the work seen in the research trip to South Korea and Japan evoked a similar indefinable sense to the works in *TRA: Edge of Becoming*, however, what became most pertinent was the Eastern approach to the materials which enabled the artists to transmit the indefinable, elusive, underlying roots of reality to others. This became a model for the material investigations that interrogated the properties and behaviours of the materials used to create art for this research (see Chapter 8) which contributed to the knowledge of these materials and then provided a basis for creating the artworks and installations.

The next chapter discusses individual artists in the field whose work parallels the artworks in this research and serves as part of the literature/contextual review.

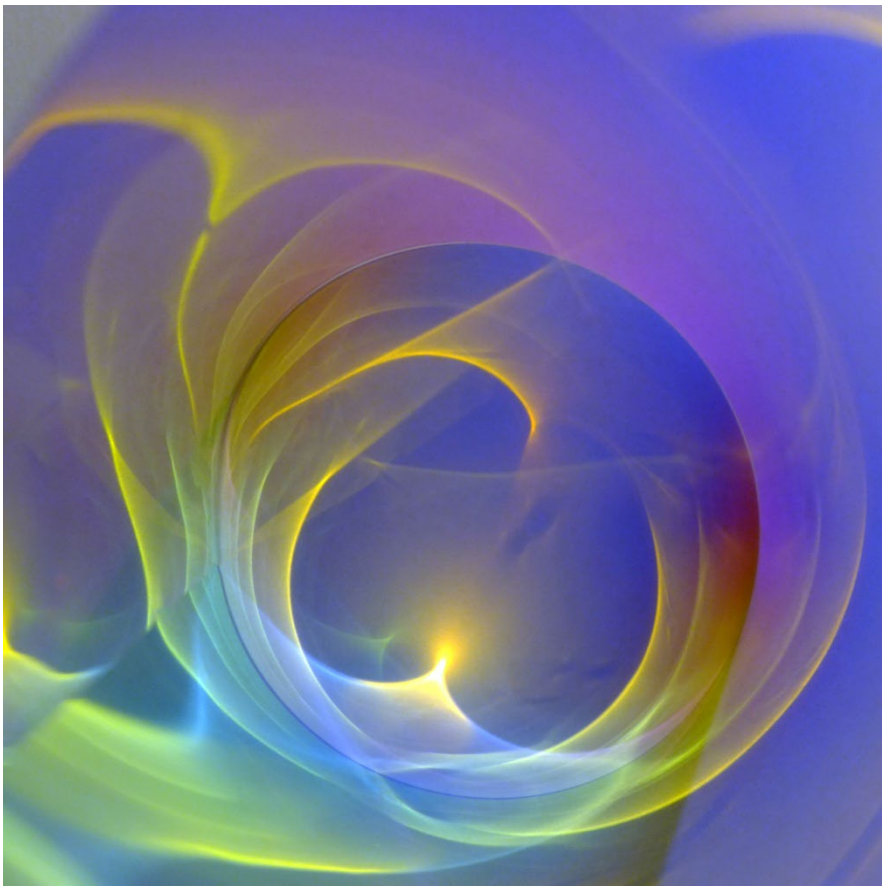

Image 25: Dichroic film, sunlight. 2018.

Part I—Artists in Context

Chapter 2
Light Materials—Artists and Light

The contextual review of relevant artists in the field is situated in three places in this text. Firstly, the previous chapter recounted the initial artistic inspiration for this research which raised many of the themes that influenced the subjects of this enquiry and introduced the role that materials, materiality and immateriality play. Secondly, the current chapter reviews selected light-inspired artists that construct an artistic and historical context that includes both predecessors and contemporaries. And thirdly, in *Part III—The Science of Light: Unravelling Threads of Influence,* Olafur Eliasson's use of moiré is discussed in Chapter 6 and artists inspired by physicist David Bohm are discussed alongside a consideration of his theories in Chapter 7.

Many light-inspired artists root their work in a scientific understanding of light which, in turn, activates many of the significant and relevant themes, such as questions of dualities, wholeness, boundaries and the dissolution of form. Sîan Ede writes in *Art and Science* that, historically, many artists who "subscribe to the idea that there was a hidden order beyond all things" were inspired by science to explain their methodologies or spiritual revelations and look more deeply into the hidden mysteries of the universe (2008: 37). The representative artists in this chapter were chosen for their similarities to the current study and to reflect and reinforce its discoveries and positions, including using light as a medium and employing similar optical materials, such as using prisms and mirrors.

Historically, modern light art emerged alongside the development of artificial light, for example, with experimentation by artists of the Constructivist and Bauhaus movements. An early pioneer in this field, László Moholy-Nagy, serves as a case study below. A second case study looks at the contribution of contemporary Light and Space artist, Larry Bell. Many aspects of the work of both artists parallel the subjects of this enquiry and as in this research, they have an experimental approach to materials or processes thereby pushing the materials' conventional limits. Due to its nature and the properties of light, working with it in this way produces innovative processes and novel outcomes.

Recently, the contemporary field of light-inspired art has become prevalent, indicated by the many large exhibitions featuring light in recent years. Two examples held in London were *Light Show* at the Hayward Gallery in 2013 and *Shape of Light: 100 Years of Photography and Abstract Art* at the Tate Modern in 2018. Amongst the artists

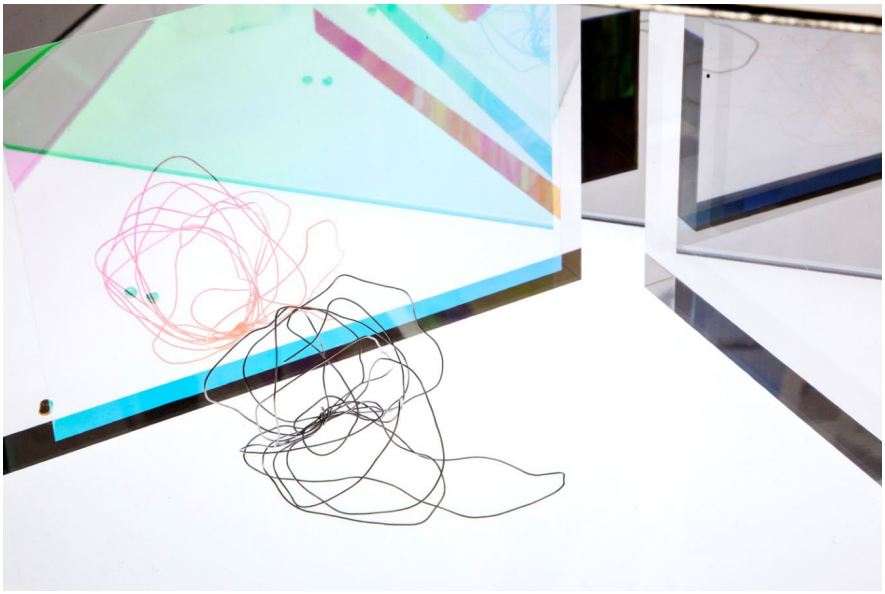

Image 26: *Unfolding Light and Space #1. Detail view.* Prisms, two-way mirror, wire, gold beads, LED panel. Photograph by Ibolya Ferher. 2015.

represented at these exhibitions, many use optical materials such as mirrors and prisms to exploit the properties of light such as reflection and refraction defined by classical physics. These artists include Alyson Shotz, Josiah McElheny and Brigitte Kowanz who considers light to be a form of language—a carrier of signs and codes. Kowanz observes that mirrors conduct and intensify light; they "can transmit light, can reflect and bend it, and they can open up spaces and dissolve boundaries" (cited in Luckett 2013:120). Many light-inspired artists raise the question of boundaries and, in this enquiry, this is approached in two ways, firstly, through the lens of classical physics by using mirrors and prisms, and secondly, through attention to revealing the paradoxical characteristics of light described in quantum physics by employing diffraction grating and dichroic materials (see Part IV).

László Moholy-Nagy

László Moholy-Nagy's influence is significant here, for both his dedication to light and his experimental approach to materials and media. He was one of the primary pioneers of light art, with light being the foundation of his artistic work throughout his career. He had an innovative approach which included exploring reflection and refraction through attention to surface and transparency. Many of the themes that emerged for Moholy-Nagy are significant for the current enquiry, including holism, the observer's interrelationship with the work, kinetic optical composition, non-representational forms, 'drawing' with light and taking inspiration from science (see Part IV).

Moholy-Nagy's first expression of his lifelong obsession with light occurred in his poem, 'Light Vision',

> Learn to know the Light-design of your life.
> You will find it different from chronology.
> A different measure, called Eternitas,
> Proud battle for the secrecy of order.
> Space, time, material—are they one with Light?

Light Vision, László Moholy-Nagy, 1917
(Source: Sibyl Moholy-Nagy (1950).

The concepts explored in his poem were to obsess Moholy-Nagy for the whole of his artistic life and serve as a leitmotif for this research. His question "Space, time, material—are they one with Light?" is central and was intrinsically key to broadening the scope of the current study to primarily use light itself as a vehicle to interrogate space and materiality. The poem was personal to him and was only published after his death in his wife's biography, *Moholy-Nagy: Experiment in Totality*. This poem was written after his battery had been wiped out during World War I; he was the sole survivor, critically

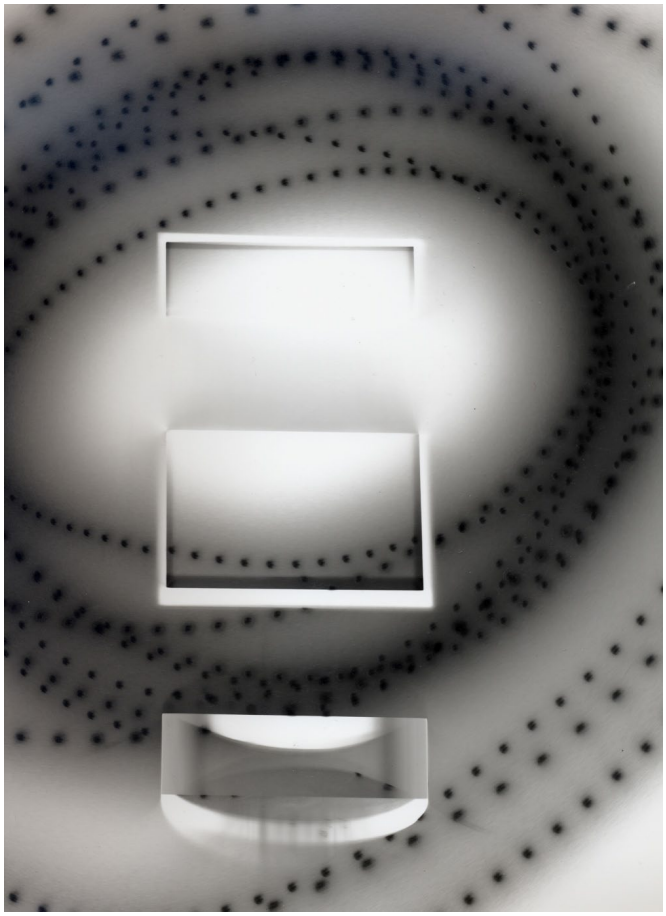

Image 27: Scan of photogram, three prisms, light from presentation laser pointer. 2015.

wounded and experiencing a delirious altered consciousness. Sibyl expresses the profound significance of light for László,

> Early in 1917 he had crystallised a philosophy of vision. He was twenty-one years old then, isolated from his fellow men, and suffering bitterly from his ill-treated wound. Between fever deliriums he wrote the creed of his life (Moholy-Nagy 1950:11).

The poem's full text (Moholy-Nagy 1950:11-12) shows that Moholy-Nagy had an early and profound understanding of dualities—light/darkness, chronological time/eternity, order/chaos, everything/nothingness, eternal/death. He brought this understanding to bear in his art practice, where, for example, light and shadow were essential components in his artistic expression of time-space. As in this research, using dualities was a helpful way to express complex concepts—one part cannot exist without its opposite, each serving to describe the other and define the whole.

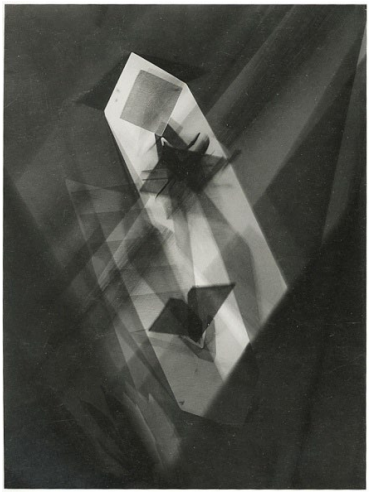

Figure 1.
Untitled. 2005.
László Moholy-Nagy.
Silver bromide gelatin photogram.

Photograms and Drawing with Light

Moholy Nagy was an early originator of photograms (a form of camera-less photography) created by using light and shadow where light is shone over objects and materials placed directly onto a photosensitive plate or paper. Moholy-Nagy and Man Ray both developed photograms simultaneously; however, their artistic motivations and strategies differed. Man Ray created his *rayographs* from a surrealist standpoint where the role of chance enabled a release from the constraints of the rational world—Moholy-Nagy, on the other hand, had a more scientific motivation based on physics and optics. This research aligns with Moholy-Nagy's view, and an example of how his photograms inspired the photogram investigations made for this research is described below.

To create his photograms, Moholy-Nagy laid objects onto photosensitive paper and then exposed them to light from a lamp to create abstract, non-figurative compositions. The black portions of the image received full light, and the lighter parts show where the objects

Image 28: Dichroic film, sunlight. 2018.

made shadows or blocked the light. To create the complex light paths above, he used prisms to reflect the light onto the paper; the grey portions trace the path of reflected light (See Fig.1).

Early in the current enquiry, photograms explored 'drawing with light', a notion which was developed later with the *Ensō* (see Chapter 1)*, Drawing with Light* and *Light Dance* series (see Part IV). The image of the photogram on the previous left-hand page was created for this research by placing three prisms on photosensitive paper. In going beyond the normal limits of the photogram process, developing new directions, the light source used was not a lamp but a presentation 'laser' pointer. The print captured the movement of this light source as it was swung in circles above the light-sensitive paper. Surprisingly, the light from a pointer is not a continuous flow as expected—a true laser light would have been exposed as an unbroken line. It transpires that the 'laser' light is, in fact, light emitting diode (LED) light pulsed faster than the naked eye can detect and is captured as a trail of dots or 'particles' on the photosensitive paper. These particles have diffuse edges, their boundaries dispersed (caused by interference from the light from the laser pen rebounding from the surface of the photosensitive paper itself) and are suggestive of physicist Basil Hiley's descriptions of quantum particles as localised regions of energy (2021b). Here, both the particle and wave natures of light are visually expressed through the rhythmic, concentric trail of dots around the crisp prismatic forms, the organic spiral interrupted by their hard-edged forms

Careful observation shows that, surprisingly, there are places where the paper below the transparent prisms remained unexposed, staying white following the developing process. This suggests that the prism had opaque sides that did not allow the light to pass through; however, we all know that prisms are transparent and should not impede the passage of light. This illusory opaque phenomenon was caused by the light being reflected away from the internal edges of the prism, preventing it from hitting the paper (this property of prisms is explored fully through the material investigations in Part IV).

Two artists who take different, but innovative, approaches to drawing with light are discussed below. Firstly, Garry Fabian Miller pushes the limitations of a camera-less process and 'paints' with light. In the second example, the Anglo-Korean duo Kimchi and Chips take the process beyond working on photosensitive paper to recording a halo of light reflected onto a mist.

Garry Fabian Miller explores light, time and colour by filtering and directing light through coloured glass and liquids onto Cibachrome photographic papers to form the abstract

Image 29: Black paper cut with two slits, diffraction grating, reflections of studio windows, LED light. 2018.

compositions he calls 'luminograms'. For example, *Petworth Window 13 February 2000* was created by light from the window being directed horizontally onto the photographic paper through a blue glass container filled with water acting as a filter. He placed a wooden structure to obstruct the light and form this composition. The resulting intersection of the horizontal and the vertical is a fundamental meeting of polarities. Windows are boundaries between inside and out, a transparent screen; they are openings for looking through but not passing through (See Fig. 2).

Figure 2.
Garry Fabian Miller.
Petworth Window 13 February 2000.
Dye destruction print luminogram.
Height 73.7 cm x width 64.8cm.

In a very different approach, Kimchi and Chips (Mimi Son and Elliot Woods) explored the idea of drawing in the air using sunlight and mirrors as mediums with *Halo* at Somerset House, London in 2018. When the sun was shining, it was reflected off 99 heliostats (carefully calibrated, software-controlled, motorised mirrors that followed the course of the sun), creating a halo of light suspended and floating in mid-air in a cloud of mist which emerged from groups of fine water jets. The reflected image responded to fluctuations in the weather and changes in the breeze and sunlight, inviting the viewer to examine the relationship between image and reality. The work was both transient and eternal, and they said, "The moment that Halo emerges in the air, it briefly superimposes the transience of momentary experience with the immutability of the sun" (Kimchi and Chips 2018). Rather than being inspired by science, their technological installation was inspired by Buddhist notions of interconnectedness and interdependence, exploring what they term 'immaterials' (such as light and space) and creating encounters at the borders of materiality and immateriality, absence and presence.

Moholy-Nagy and Einstein

In addition to his mystical experience of the essence and substance of light, Moholy-Nagy's focus on light was based on Einstein's theories of space-time drawn from his

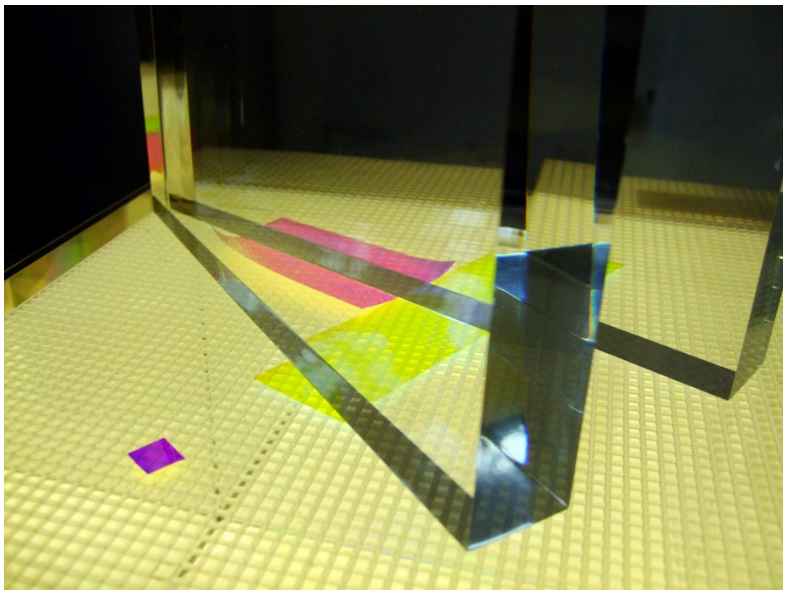

Image 30: Prisms, dichroic film, plastic mesh fabric, LED light. 2015.

theories of Special and General Relativity (Dalrymple Henderson 2008:111). In 1905 Einstein had written a series of papers that were a fundamental departure from Newton's mechanistic view on space, matter and time, transforming the way we see the universe. Troubled by the prevailing wave theory of light, he postulated a quantum theory of light—where light exists as tiny packets, quanta of light energy with particulate qualities, which he called photons. His theories fuelled the debates on the wave/particle natures of light which continue to this day.

Moholy-Nagy met Einstein in 1924 to discuss the possibility of Einstein's contribution to a popular book on relativity for the Bauhaus' *Bauhausbuch* series. Unfortunately, this was not realised as the series was never completed (Moholy-Nagy's *Painting Photography Film* being the last production in the series in 1925) (Dalrymple Henderson 2008:111). However, Moholy-Nagy was not alone as Einstein's theories influenced many of his contemporaries, including El Lissitsky and Naum Gabo (who first heard of the theories in 1911 or 1912 whilst taking physics classes in Munich) (Dalrymple Henderson 2008:114). Einstein continued to inspire 20th century artists, architects and designers to engage in an exploration of light, light-space and space-time. An example is Jim Davis, a mid-century avant-garde American painter and experimental filmmaker who sought to capture abstract patterns of light on film—light in motion.

Transparency/Surface

Moholy-Nagy explored transparency in different ways. For example, he used transparent materials directly in his photograms: glass, lenses, transparent crystals and liquids (1969:31); also, many of his paintings depict transparency with flat, abstract, geometric planes intersecting and overlaying each other. Transparency was a key revelation gained from making his early glass and metal constructions, and he described his discovery in his autobiographical book, *The New Vision and Abstract of an Artist* (1947), stating,

> I hit upon the idea of transparency as epiphany. This problem has occupied me for a long time…My work since those days has only been a paraphrase of the original problem, light (cited in Borchardt-Hume 2006:173n5).

Artists concerned with light often refer to revelations that shift the focus of their work as epiphanies, for example Larry Bell and Liliane Lijn (see Chapter 7).

Both Moholy-Nagy and Larry Bell have a lifelong interest in light's relationship to surface and how its properties can be used to make art, sharing an interest in transparency, and Bell experienced his breakthrough moment with transparency whilst experimenting with

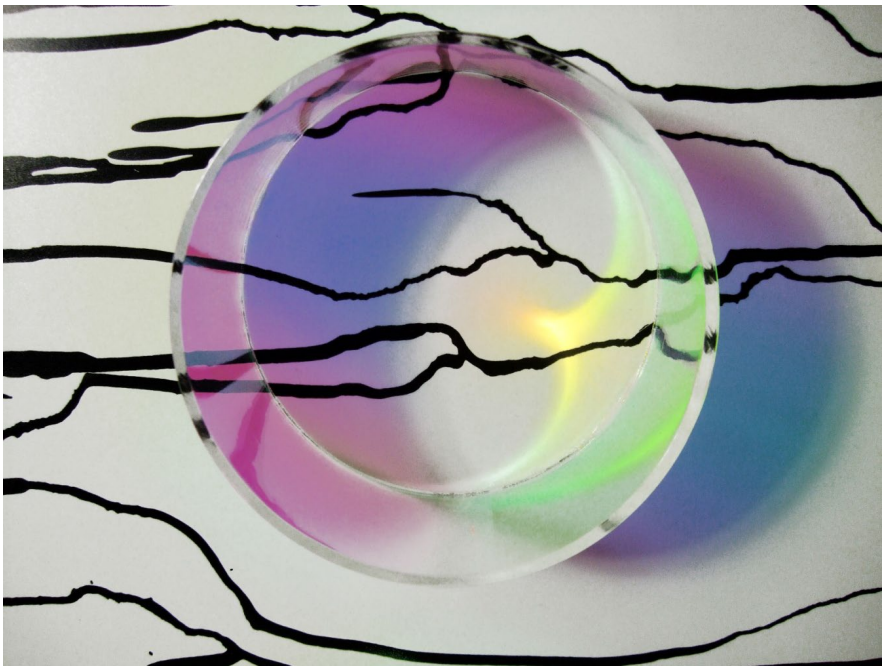

Image 31: ***Quantum Questions—Line Interrupted #7.*****Detail view. Forex, black calligraphy ink, acrylic, dichroic film, mirror, wooden frame. 2017.**

glass scraps in the framing shop where he worked. Bell was a student of Californian Light and Space artist Robert Irwin and is considered to be one of the leading Light and Space artists himself and is interested in light, space, dimensionality and illusion, exploring and interrogating both visual and physical fields of perception through the properties of light, particularly the interface of light and surface. The minimalist Light and Space movement originated in Southern California in the 1960s with artists, such as James Turrell (see below), who were interested in how light affects both the environment and perception of the viewer.

Having cracked a piece of glass in a shadow box, Bell noticed three different things: the crack itself, the reflection of the crack and the shadow of the crack. From this moment on, he began to manipulate light and the optical qualities of glass, thoroughly exploring its capacity to absorb, reflect and transmit light simultaneously (cited in Dickie & Bailey 2017). His *Glass Cube* series (vitrines ranging from two inches to 40 inches in size) manipulate how light interacts with glass, affecting perspective and surface, playing with the notion of space and questioning mass and volume. Many of Bell's large installations are composed of glass sheets that are both reflective and transparent and can be rearranged into multiple variations. As with the current research, these materials reveal and deceive simultaneously—one of the primary concerns being the visual and physical relationship between the viewer, object and its environment. Dan Graham is another artist who uses glass sheets in similar ways in his human-scale semi-reflective installations, for example, his two-way mirror *Waterloo Sunset Pavilion* (2003) *sited* on the balcony of the Hayward Gallery, London.

Parallels between Bell's art and this research include the vacuum-coated materials he uses that are similar to the dichroic film used in the current research. He pushed the limits of his materials, performing what he calls surface investigations which correspond with the material investigations for this research. For example, in the 1970s, in a body of work called *Vapour Drawings*, he started experimenting with different papers, coating them with a variety of materials. Examining the different ways light behaves using the same coatings on the different surface qualities of glass and paper led him to a greater understanding of the nature of surface and materials. He said, "I don’t want to alter the surface: I want to alter the way light comes off that surface" (cited in Dickie & Bailey 2017). He observed that glass reflects ambient light whereas paper absorbs and contains it, saying, "That was an astonishing revelation to me, that the surface quality is a deciding factor in the interaction of light with that surface" (Bell 2013a).

He commissioned a local Los Angeles-based company used by the film industry to coat his glass, however, after several pieces were damaged during shipping to his first show in

Image 32: Two-way mirror, prism, dichroic film, silvered foil, LED light. 2015.

New York in 1966, Bell purchased his own vacuum coating chamber, enabling him to manage and develop the process himself. As with this enquiry, hands-on experimentation with materials in creating artworks is key to Bell's artistic process. He could now regulate the thickness of the coatings and control the wavelengths by creating infinite variations in the colour, transparency and reflectivity of the glass. The chemicals he used interfere with the light in the same way that the iridescent thin-film interference creates patterns on the surface of bubbles. Artist couple, Evelina Domnitch and Dmitry Gelfand, exploit the optical effects of thin film interference in a different way by using bubbles. In *10,000 Peacock Feathers in Foaming Acid*, laser beams penetrate soap film clusters, and the interaction with the structures and colours of the bubbles' thin membranes are then projected at large scale (Miller 2014:124).

Like Larry Bell, a form frequently used by light artists is the cube or vitrine. Several artists have made cabin-sized vitrine installations and two were shown in the Hayward Gallery's *Light Show* 2013: *The Blind Aesthetic* by Conrad Shawcross, 2011, and *Reality Show (Silver),* 2010, by Chilean artist Iván Navarro. This smaller cabin, rather like a phone box, had half-silvered mirror walls so that observers could see inside the box; however, viewers entering the box experienced an infinite, expanded reflective space.

Many viewers expressed the desire to stand inside the artworks when looking at the small cube installations made for this research. In response to this, the human-scale vitrine, *Beyond Dualities Pavilion,* was created for the final show for this PhD (see Chapter 10). It was constructed from half-silvered mirror so that the interior could be viewed from outside the vitrine. The multiple reflections of the viewer, extend towards infinity in two directions. An artwork composed of a vortex created by a printed image layered with dichroic 'particles' formed the ceiling of the vitrine was repeatedly reflected in the mirrored walls and floor. Surprisingly, and contrary to expectations, as a result of the dichroic material, the reflected dots were not all reflected as one colour (as would usually happen) but change colour as their reflections recede into the distance, changing from magenta, through orange and yellow to green.

James Turrell

James Turrell says, “My art is about your seeing” (cited in Tomkins 2003). *Dhatu* (2010) (discussed below) is as an example of his approach, it is one of his Ganzfeld pieces—disorienting spaces with little or no shadow or horizon to focus on, where colour perception is questioned. Turrell studied experimental psychology (in particular optics and visual phenomena) and mathematics before studying art at Irvine in the 1960s. He was influenced by his tutor, John Coplans and by the work of Mark Rothko and Barnett

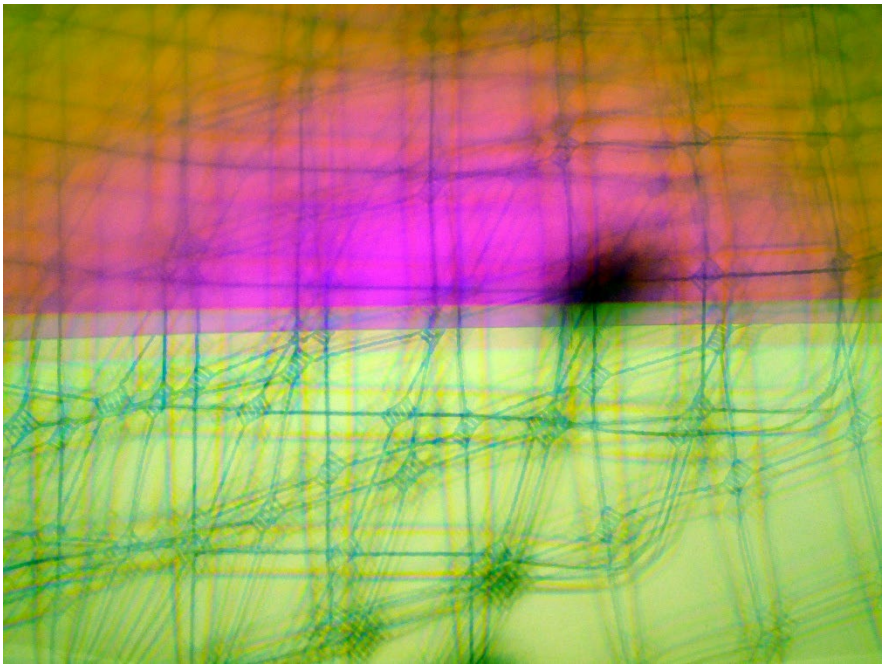

Image 33: Diffraction grating, dichroic, birdcage netting, LED light. 2019.

Newman, “whose canvases seemed to generate a kind of inner light”, explains Turrell (Tomkins 2003). He has been working with light and exploring the nature of perception ever since. He was a member of the West Coast Light and Space Movement together with Robert Irwin and Larry Bell. In the 1970s, along with artists like Anthony McCall and Robert Smithson, he advanced situational aesthetics (a term first used by Victor Burgin in 1969). He “not only marked a radical break with the regime of one-point perspectives that had prevailed in Western culture since the Renaissance, but also expanded the traditional viewing space to include active participatory fields…drawing attention to the conditions and complexities of perception” (Biesenbach & Marcoci 2007:184).

Turrell explains,

> I make spaces that apprehend light for our perception, and in some way gather it, or seem to hold it. So in that way it's a little bit like Plato's cave … We have the physiological limits of perception, and then we have this cultural overlay which is a learned perception. They are not identical at all. Some of Plato's references are to that as well (Whittaker 1999).

Historically experienced fixed perspectives are challenged by some of the artworks in this research, for example in the Unfolding *Light and Space* series (see Chapter 10).

At first sight *Dhatu* appears to be a large rectangular projection of monochromatic light on the wall above a stepped pyramid structure which is slowly changing hue. However, closer examination reveals that this is a doorway to a coloured room-space. Perception is similarly challenged once one is inside the space as the side edges are rounded and not defined by shadow and do not provide a spatial reference. However, the far wall, being different in colour to the rest of the space is clearly discernible. However, this too is an illusion as it is not a physical wall but an opening into a larger light-filled chamber beyond. This clearly demarked division of the space by the light is not determined by visual clues but by haptic sense—on reaching out to touch this substanceless wall, one encounter only empty space. As with the current research, light affords illusion.

What we sees within the rectangular doorway is the complimentary colour to the one currently radiating into the room-space. Intellectually, we know that, though we see it, this vivid colour does not actually exist and has been created solely by our own mind, a perceptual illusion. Olafur Eliasson creates similar illusions using light and afterimage effects with pieces like *360° room for all colours*, 2002 (see below). Moreover, the viewer’s sensory input is minimised while they are inside *Dhatu*, opening up peripheral vision. Architect Juhani Pallasmaa explains the consequence of peripheral vision thus, “Unconscious peripheral perception transforms retinal gestalt into spatial and bodily experiences. Peripheral vision integrates us with space” (2005:13).

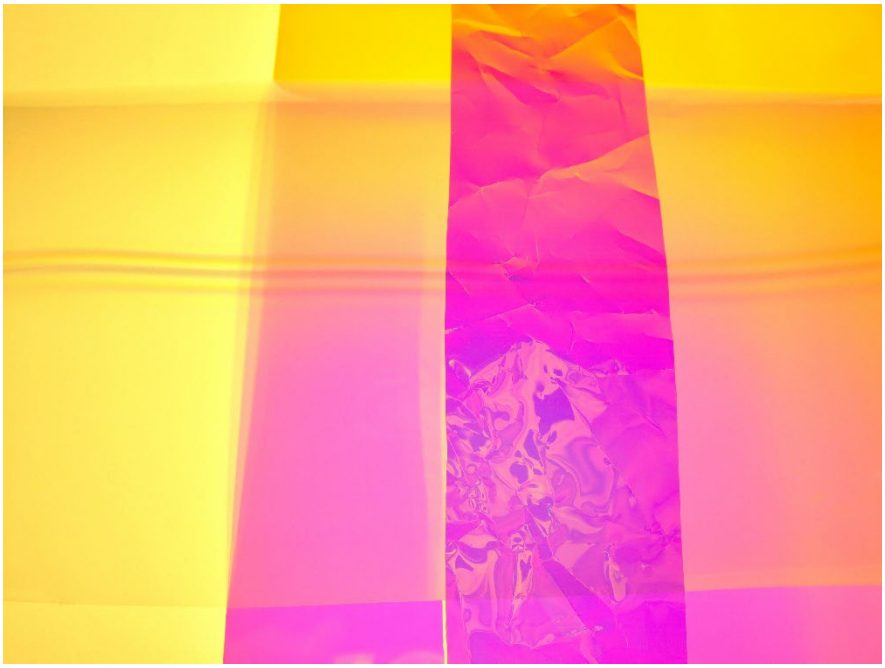

Image 34: Diffraction grating, dichroic film, wire, LED light. 2018.

Turrell successfully creates perceptual uncertainty by raising many experiential questions from the viewer, primarily, ‘What is material or immaterial?’ and ‘Is seeing believing?’ On engaging with the new environment of *Dhatu* one assimilates the new sensory information and re-orders, what Turrell terms, our ‘prejudiced perception’ (Whittaker 2001): above all, we see ourselves seeing.

Figure 3. Installation view of *Dhatu* James Turrell, Gagosian Gallery. 2010. Photograph, Florian Holzherr.

Olafur Eliasson

Eve Blau (2010) observes that Eliasson is well acquainted with Moholy-Nagy’s spatial experiments “into a fully three-dimensional exploration of the multilayered co-existence of space, time and consciousness in human perception, relations, and actions”. Eliasson’s work connects to Moholy Nagy and to the investigations for this research through his exploration of light and transparency and his use of mirrors and prisms for optical effects.

Although his work does not gain its meaning by referring to art of earlier periods (Upsprung 2008), Eliasson he says that, in the late1980s he was inspired by the Californian Light and Space artists, including Robert Irwin, James Turrell and Maria Nordman (Eliasson and Irwin 2006:59). Notably, Turrell’s work inspired Eliasson’s use of afterimage effects.

As with the current research, the phenomena of light is a recurring theme and its nature is explored by using optical effects and an array of materials, including mirrors, lenses and prisms. Light is only one phenomenon that Eliasson investigates, others include fog, water, weather, sound, soil, fire and ice; he brings the atmospheric meteorological effects indoors, creating a constant dialogue between the internal and the external (Stafford 2009). Similar to the material investigations in this project, his works are “experimental setups: they are structures with which visitors can engage”, however they examine time as well as space and light (Eliasson & Irwin 2007:51).

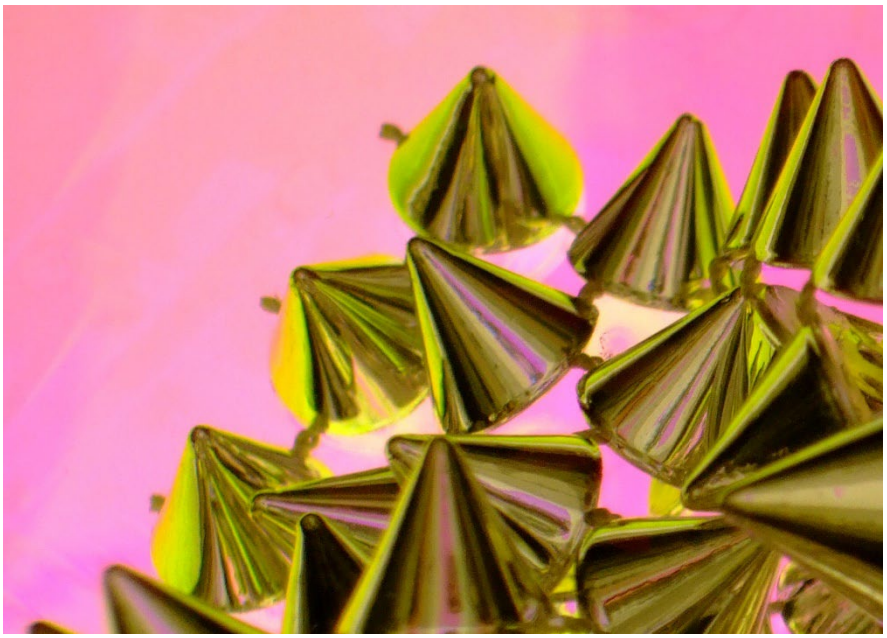

Image 35. Dichroic film, silver stud cones, LED light. 2018.

Figure 4. *360° room for all colours*.
Olafur Eliasson. 2002.

Eliasson was also influenced by the philosophy of Henri Bergson—the ultimate reality is changing rather than unchanging. His art is characterised by an exploration into the nature of things and is influenced by his studies of the phenomenology of Martin Heidegger, Edmund Husserl and Maurice Merleau-Ponty. He says,

> To me the greatest potential of phenomenology lies in the idea that subjectivity is always susceptible to change … It offers an inquisitive, explorative approach to the world that allows for multiple perspectives on artworks, subjectivity, and experience (Eliasson and Irwin 2007: 51-2).

With this dualities are challenged. Jonathan Crary (1997) writes that encountering many of his works is a whole body spatial experience which is "freed up from its habitual co-ordinates of subject/non-subject, interior/exterior, centre/periphery to become intensive, shimmering and unanchored." His work is fundamentally about perception: Crary observes that Eliasson's work is rooted in exploring and expanding human perceptual capacities creating situations for "perceiving yourself perceiving" or "seeing yourself seeing" phraseology he took from Robert Irwin.

Eliasson identifies the spectator as the 'user' rather than 'viewer' of the artwork. He constructs conditions or situations that he calls "a kind of machine, a phenomenon maker" that demands engagement on the part of the viewer/user (Eliasson and Irwin 2007:58). In a piece like *Beauty* (1993) everyone sees a different rainbow because the spectrum is created by the relationship between the angle of the light drops of water and the eye. Eliasson poses these questions, "Who has the responsibility for seeing what we see? Is it about sameness or is it about differences? Is it about every time you take a step you see something different? This is the same for everything we see" (MoMA 2008b).

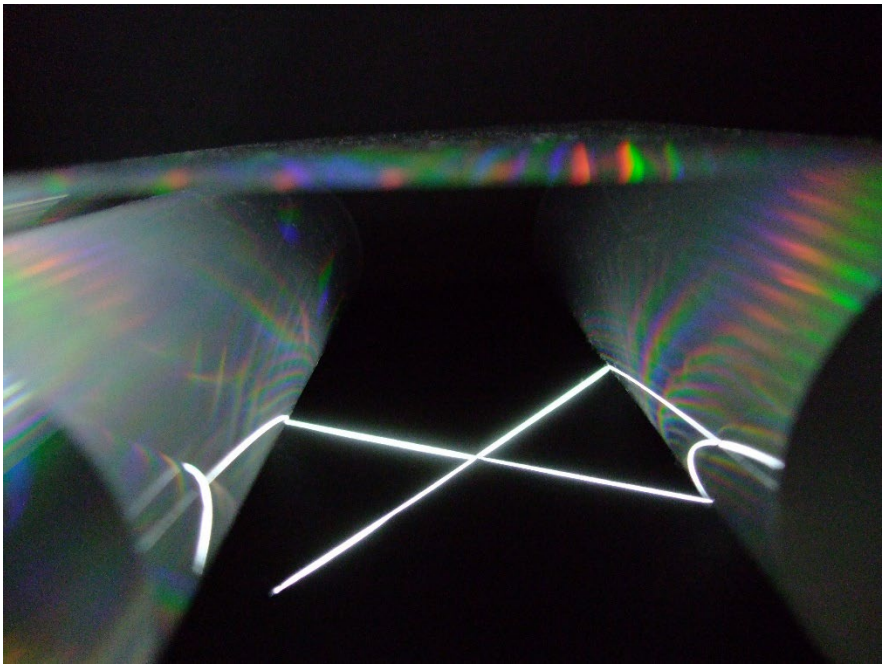

Image 36: Diffraction grating, Black paper. 2018.

Figure 5. *Beauty*.
Olafur Eliasson. 1993.

Architectural historian, Philip Ursprung (2008) states that, like Henri Lefebvre (who was opposed to the separation of phenomena and advocated interaction), Eliasson seeks to synthesize rather than analyze, preferring to create specific, complex situations rather than to separate disciplines and practices. This attitude extends to the huge Berlin studio he describes as being “like a laboratory” (Jones 2007).Teams of craftsmen and specialised technicians, architects, artists, archivists and art historians collectively work with him to experiment, develop, produce, and install artworks, projects, and exhibitions, as well as archiving, communicating, and contextualising his work. More than his scientific approach to the investigation of phenomena, Ursprung (2008) considers this studio to be Eliasson’s most important difference to his contemporaries, where he “creates syntheses of differing attitudes and points of view without subjecting them to a utopian perspective”.

Unlike artists like James Turrell, Eliasson adopts the Postmodernist quality of exposing the making of things and reveals the techniques of production and operation of the perceptual effects, for example, the lamp and the sprinkler nozzles in *Beauty* are not concealed. This exposure of the making of the work is one of the features of his work which prevents it from being a mere spectacle (Blom 2006). Conversely, many works created for this research pivot on concealing the source of an optical effect, thereby confounding the viewers, such as the *Indeterminate Interfaces* series where dichroic film is secreted between the prisms and unexpectedly casts coloured light on to the walls of the gallery—the source of these colours is not apparent.

Through the lens of semiotics, Barbara Stafford (2009) asserts that Eliasson’s work “is operating under the symbology of the prism” and attaches a historical lineage of metaphors for mirrors and optical devices to his work. However, as Ursprung (2008) notes, Eliasson is more concerned in breaking down barriers between objects and symbols and that he has no interest in signs and symbols. He is more interested in the

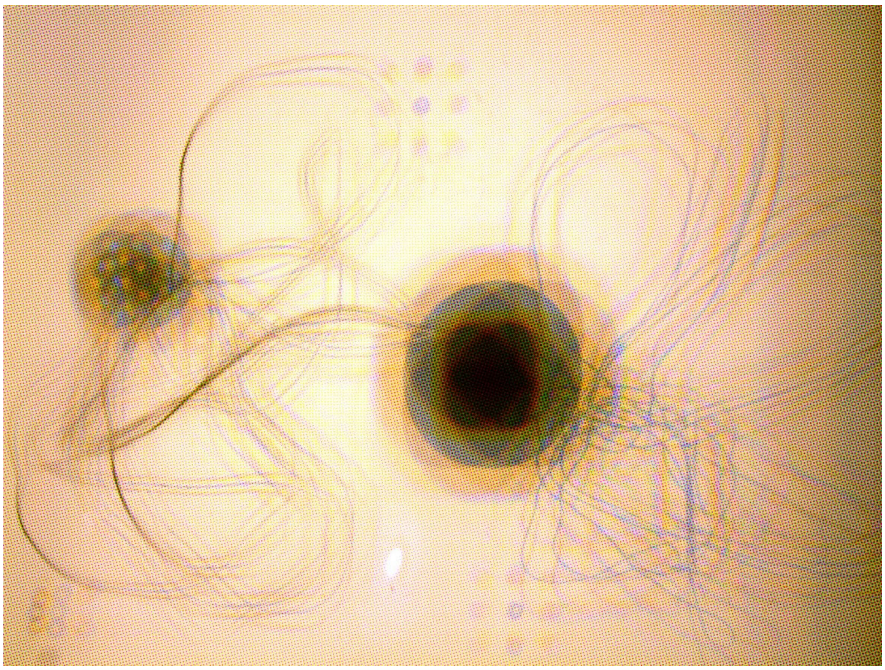

Image 37: Diffraction grating, wire, button, disc, beads, halftone process. 2019.

way in which people relate to each other and their environment, light is one of the tools he uses to achieve this.

An exploration is of moiré effects is one of the outcomes of the investigation of light in this research. Eliasson introduced moiré into his works in 2004 with *Triple ripple, Concentric mirror* and *The uncertain museum* and re-introduced it in 2022 on a grand scale in *Your view matter* and *Under the weather* (discussed further in Chapter 6).

Artists and Quantum Light

Quantum aspects of light, including wave/particle duality, entanglement and interference patterns, highlight the paradoxes at the heart of the quantum domain and are key to this research. In his essay, 'From Symbol to Substance: The Technologies of Light', written for the Hayward's *Light Show* catalogue, Philip Ball (2013:51) weaves together and summarises some salient points about quantum light. He says that light carries information and meaning and questions old certainties, that it is about illusion and our perceptual construction of the world and causes us to question our senses. These characteristics thread throughout this text and the art made in the course of this research.

The 'observer effect' and quantum entanglement originate from the two-slit experiment, as does wave/particle duality (see Part III). Other artists have drawn inspiration from wave/particle duality and two are described here. The first, an artwork, *Visualisability* (2010), from collaborative art project between artist Fiorella Lavado and scientist Arthur I. Miller, *Weaving the Universe: From Atoms to Stars* (Miller 2014:136-139). The aim of *Visualisability,* a floor-to-ceiling textile sculpture consisting of ultra-thin threads of stainless-steel wire wound into 'woven' forms, was to evoke the duality and blending of waves and particles of light and matter precisely (Miller 2014:137).

Secondly, Keith Tyson found inspiration in CERN and was awarded the Turner Prize in 2002 with an entry that included twin paintings making up *Bubble Chambers: Two Discrete Molecules of Simultaneity.* The two virtually identical paintings presented two concurrent pathways through time; atomic-like coloured circles bearing the same date stamps were overlaid with different short texts describing simultaneous events. He says, "Stuff happens at the edge of a cloud, at boundaries between countries. But reality is beyond all that—reality doesn't care about boundaries" (Miller 2014:153). Emphasising Tyson's approach to the object and the observer, Ariane Koek writes in the *CERN Courier*,

> [H]e is interested in the way that we make sense of the world: as the observer and the observed; the viewer and the artist…In essence, we are all in this artistic

Image 38: Cut black paper, diffraction grating, reflection of studio windows, LED light. 2018.

> experiment together, discovering who and what we are in the act of looking—the artist included (2010).

In response to the quantum 'observer effect', this research highlights the entangled role of the viewer which is discussed in several chapters below, where lenticular prints, mirrors and prisms, diffraction grating and dichroic materials are used to interrogate a viewer's perception and a fixed viewpoint. The use of these materials explores and presents the paradoxical nature of quantum phenomena and, although discussions of the use of diffraction grating and dichroic materials in this project are in Part IV of this text, examples of two artists using each of these materials are discussed here.

Artists Using Diffraction Grating

Artists do not commonly use diffraction grating; nonetheless, it was used to significant effect by Kimsooja in *To Breathe: Bottari* which was an installation at the South Korean Pavilion in the 2013 Venice Biennale. All the windows of the glass building were lined with sheets of diffraction grating, creating an immersive experience of light, space and colour within the pavilion which diffracted natural sunlight into rainbow spectrums of light and altered with the changes in ambient daylight. It was installed alongside a second piece, *To Breathe: Blackout,* which was an anechoic chamber—i.e. it was in complete darkness and absorbed all sound. With the juxtaposition of both installations, she invited the viewers to experience the dual qualities of light/darkness, sound/silence and known/unknown as connected parts of a whole.

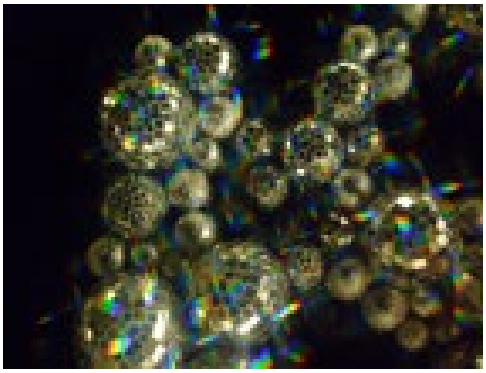

Figure 6.
Dream of the Waterway.
Sae Yoshioka and Ryota Suzuki.
Kobe Biennale, 2015.
Photograph Peta Jacobs.

A second installation using diffraction grating, *Dream of the Waterway*, by Japanese artists Sae Yoshioka and Ryota Suzuki, was situated in a darkened shipping container at the Kobe Biennale, 2015. The installation was formed of a pool of water lit from below with several glass-topped 'stepping-stones' covered by diffraction grating. Clusters of mirrored balls of various sizes floating freely on the water could be seen through the glass. The light reflecting from their mirrored surfaces passed through the diffraction grating, creating

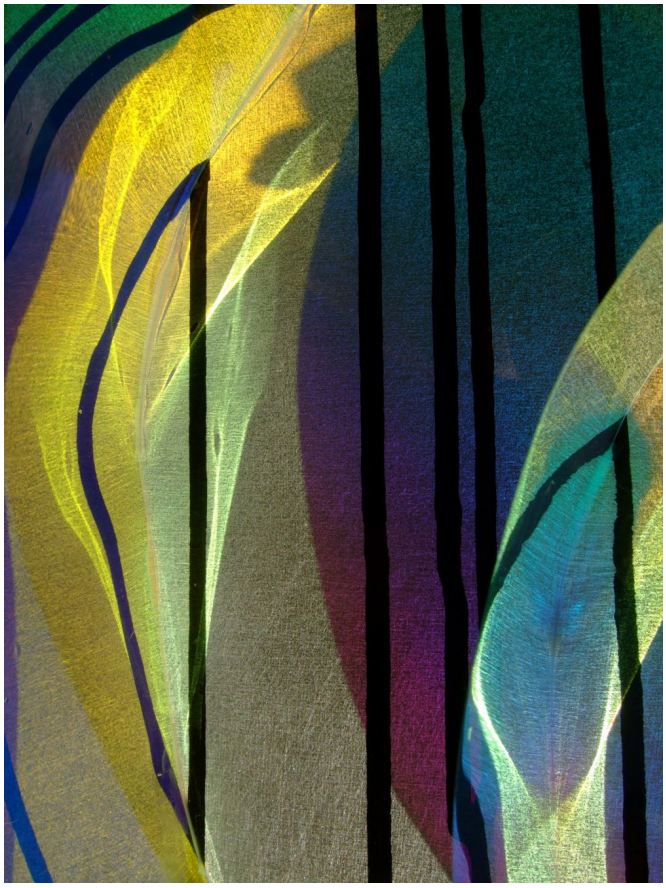

Image 39: Black ink lines on silver substrate, dichroic film, sunlight. 2018.

mini spectrum flashes offering a phenomenological experience of light bouncing off the moving mini-mirrors and bursting into its spectrum colours (See Fig.6).

Artists Using Dichroic Materials

Inspired by Isaac Newton's seven-fold colour spectrum, Liz West replicates white light dispersing through seven large-scale prisms in her installation, *Our Spectral Vision* which invites visitors to explore their relationship with, and understanding of, how we see colour. She used dichroic glass and LED strips to create an immersive environment by flooding the room with a luminous range of colours (See Fig. 7).

Figure 7.
Our Spectral Vision. 2017.
Liz West.
Photograph Peta Jacobs.

Another artwork created by the multi-coloured effects of passing light through glass dichroic prisms was *Dichroic Blossom* by Jason Bruges Studio (2014). It was an interactive installation created using LED light engines, bespoke mirror optics, dichroic prisms, an Internet Protocol (IP) security camera and a control system with an algorithm that simulates the 'growth' of plum blossom across a large wall. Groups of the LED lights reflected and refracted light through the prisms, casting and unfolding coloured rays that burst forth in patterns that changed in response to people standing near the wall (see https://www.jasonbruges.com/dichroic-blossom).

*

In the current enquiry, light is used as a material and draws on the science of light on both the classical and quantum physics levels. The artists selected for this chapter provided a context for this research as they have many correspondences and several themes that emerge when artists working with light were identified. László Moholy-Nagy was influenced by the science of light and made art using light and his work is also *about* light. Secondly, Larry Bell's artworks centre on light, transparent, semi-transparent surfaces and dichroic materials; the cuboid form of vitrines he uses is common to both. In addition to addressing qualities of optical materials such as transparency, themes identified include,

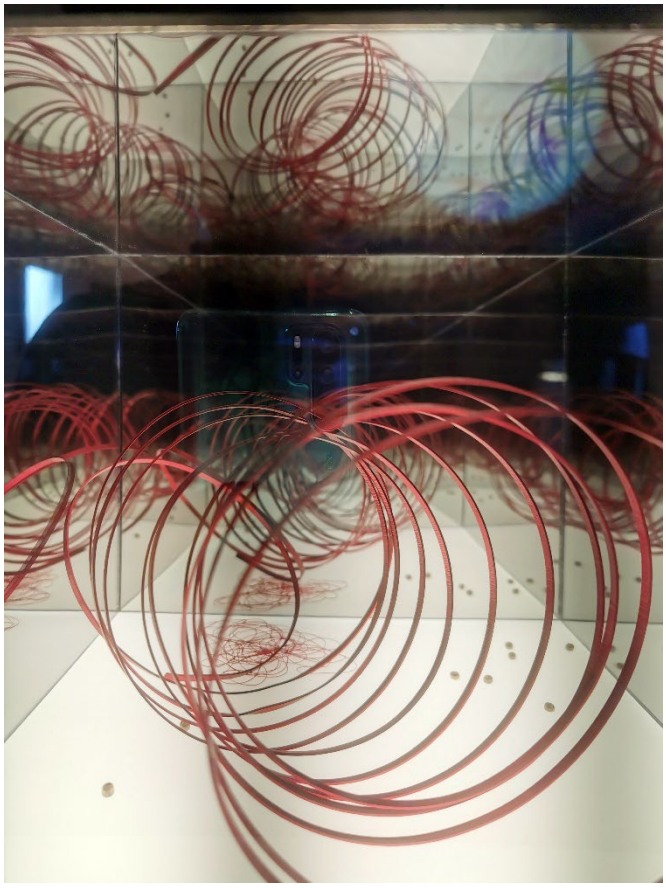

Image 40: Half-silvered mirror, LED light panel, red wire, beads, red thread. 2018.

different processes of drawing with light. The works for this enquiry differ from Bell's as the themes they incorporate emerge from quantum physics and include, wave/particle duality and the role of the observer/viewer.

The next chapter, *Chapter 3: Framework and Rationale—Tangled: A Crisis of Perception,* outlines the principles of Systems Thinking which offer a framework for the approach of this research.

Chapter 4: Braided—Art Practice as Research and Soft Textile Thinking, the second chapter in *Part II—Methodology*, discusses how the methodology of art practice as research founded on textile thinking effectively manages the complexity, multiplicity and interconnectivity of all these elements with metaphors of braiding, weaving, folding and entanglement.

A quantum investigation of light has wider philosophical implications, and these are interwoven throughout the thesis and the works themselves. The three chapters in Part III look at different aspects of the science of light that thread through this research and are embedded in its artworks. Part IV discusses the art practice and demonstrates how this research entangles all these elements, science, philosophy, Eastern thinking, art and materials, in its approach to light.

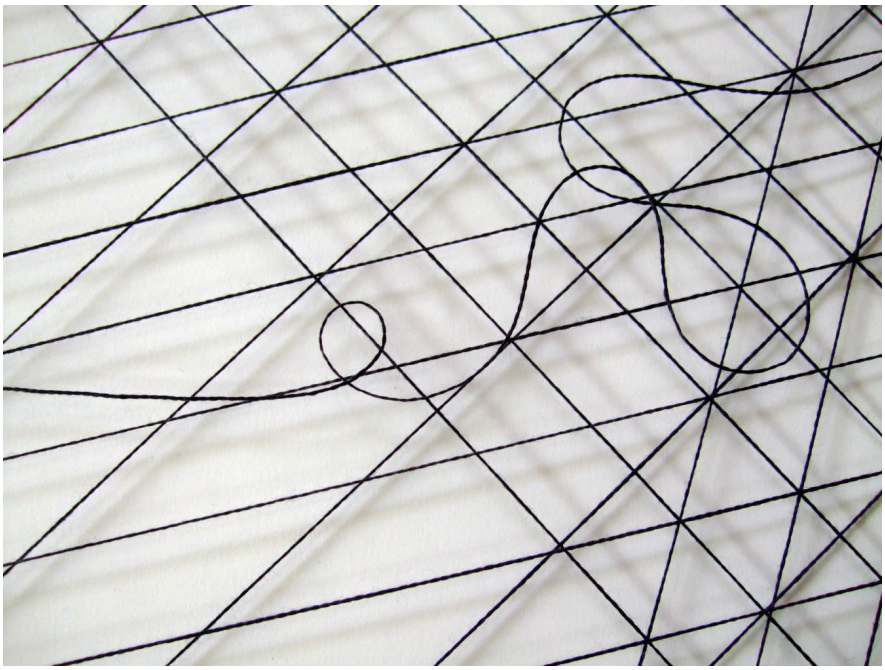

Image 41: Black thread held by pins, white board. 2016.

Part II—Methodology

Chapter 3
Framework and Rationale—Tangled: A Crisis of Perception

Physicist Fritjof Capra's Systems Theory disrupts linear thinking and provides a useful contextual worldview and methodological framework for the current research. Moreover, it aligns with the rationale behind this research in many ways. Eight characteristics are identified by Capra and Luisi, how they relate to this enquiry are listed below.

The revolutionary discoveries in quantum physics supported the development of Systems Thinking by giving rise to a view that the universe is an interconnected web of relationships whose parts can only be defined through their connections to the whole (Capra & Luisi 2014:79). Capra suggests that the root cause of the multiple global crises (political, ecological, environmental, social and economic) we face is that they are not separate issues to be solved individually, rather, they are interconnected and interdependent systemic problems (2014:362). Although the issues are composite and tangled and cannot be understood in isolation, Capra has argued for more than twenty-five years that these issues are expressions of a single crisis which he identified as a "crisis of perception" (1996; 2014:xi; 2014:363). This crisis of perception derives from an outdated worldview that does not consider these problems to be interrelated. He advocates a systemic view that includes and integrates a range of arenas (biological, cognitive, social and ecological and has profound philosophical, spiritual and political implications). He argues that an integrated systems approach would have far-reaching effects that will,

> trigger a shift in consciousness that will enable us to radically improve the quality of our lives and the health of the ecosystems and planet we inhabit. It will change the ways we relate to each other and the rest of the natural world and allow for the emergence of health as a systemic property linking human and planetary health (1996:4).

David Bohm also called for a shift to a holistic viewpoint in order to challenge rooted perceptions that have led to a fragmented mode of thought (1980:1-26; Bohm & Peat 2000:15-25). He writes that fragmentation originates from the ego's identification of a self as being separate from reality and derives from focusing on particular problems without attending to the wider interconnected contexts in which they are embedded (Bohm & Peat 2000:12). As a solution, he suggests that "The challenge is to dissolve this old pattern of thought and perception rather than to try to contradict it, to control it, or to destroy it byforce, or by will" (1985b:150-153). I concur with Bohm, who believed that many

Image 42: Installation view. Arnolfini, Bristol. Photograph Naomi Wood. 2019.

problems currently facing humankind are rooted in a reliance on thinking primarily governed by reason and individualism and dualistic thinking, and the idea that the way humans solve things is to destroy each other. Navigating the knotty problems differently requires a perceptual shift, a novel kind of enfolded systemic thinking that reconciles opposites, reuniting the splits between body and mind, science and spirit, reason and intuition. Such holistic arguments can point us towards a fresh way of forging solutions. Although shifting perception is not easy to accomplish, Capra argues that taking a Systems View of life is an essential step towards addressing this crisis of perception as it allows a crucial shift in thinking towards a holistic and view (2014:xi; 2014: 363). Capra's notion of a *single* crisis reduces seeking manageable solutions to the many problems to a single (and therefore more readily attainable) approach. I agree that there is a need to transform perception towards a holistic worldview, and this is an underlying motivation in the creation of the artworks where, for example, many dualities are reconciled or questioned—positive/negative, interior/exterior, large/small.

The Role of the Artworks in Shifting Perception

Based on the assumption that a shift in perception towards a holistic viewpoint can occur in the brain's Reticular Activating System (RAS) by receiving information directly through the senses, I argue that a shift in perception can occur by viewing artworks that embody principles of wholeness and other characteristics of systemic thinking (discussed below).

The artworks introduce unexpected and unfamiliar sensory experiences that impact the RAS because their novelty interrupts our expectations of what we see (Seth 2018). This is evidenced by frequent comments made by people while viewing the artworks, such as "What am I looking at?" or, "I've never seen anything like this before". Therefore, the works are a site for making and remaking perceptions of the world by challenging prior fixed beliefs, viewpoints and assumptions at a subliminal level. In this way, viewing the artworks can alter the perceptual database in our brains, enabling a shift in perception towards ideas of wholeness, interconnectedness and unification of opposites, potentially leading to breakthroughs in perception.

The works do not specifically address or engage with the aforementioned global problems themselves; however, by actively questioning the viewer's perceptions, they act directly on the perceptual apparatus of the brain and offer a site for a shift in perception, loosening fixed beliefs based on a mechanistic and fragmented worldview. They challenge the belief that we are separate—our sense of separateness is an illusion because, ultimately, everything is interconnected—we are not isolated individuals and cannot step outside the whole, which means that the world's problems do not exist outside ourselves.

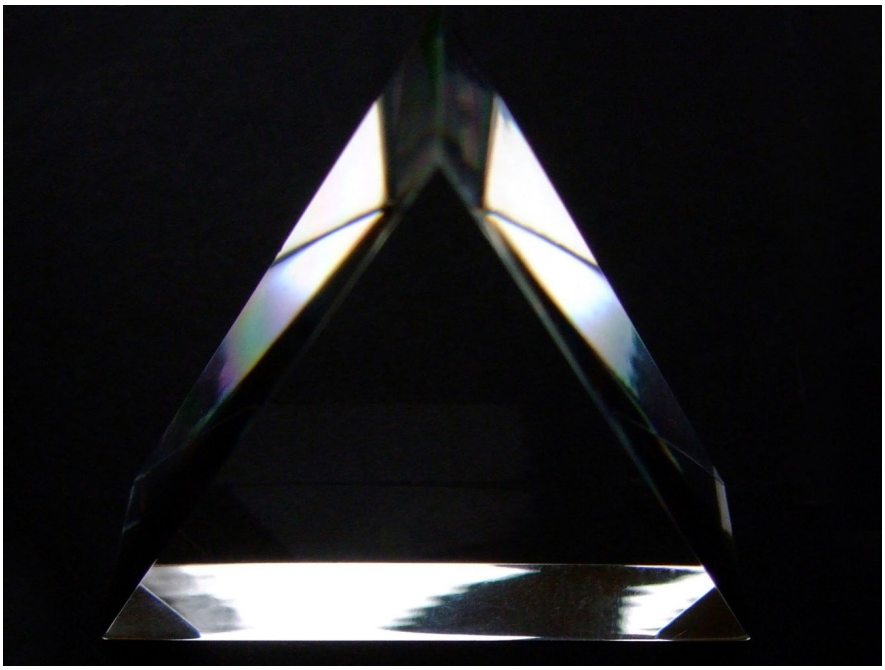

Image 43: Prism, black paper. 2015.

Understanding our interconnectedness with everything encourages us to act with impartiality and a greater sense of responsibility and awareness.

Drawing on the words of Gilles Deleuze, "Something in the world forces us to think. This something is an object not of recognition but of a fundamental *encounter"* (1994:139), Simon O'Sullivan expands the distinction between an object of recognition and an object of encounter (2005:1). He states that there are two kinds of artworks, representations and encounters, and he adds that they affect us differently. As O'Sullivan states, no thought occurs with an object of recognition as it represents something always present; therefore, our knowledge, beliefs and values are reconfirmed and reinforced as it is a habitual way of being. On the other hand, an art encounter challenges our accustomed ways of being and disrupts our knowledge systems and we are forced to think. It both ruptures our habitual modes of being and offers possibilities for seeing and thinking differently. He says, "Art is this complex event that brings about the possibility of something new" (2005:2) and he continues, saying that art encounters force us to think and question accepted assumptions about the world. The artworks made for this research are, by this definition, encounters that invite the viewer to engage and question their own perceptions experientially.

Characteristics of Systems Thinking

In *The Systems View of Life: A Unifying Vision* (2014), physicist Fritjof Capra and professor of biochemistry Pier Luigi Luisi offer a framework for a novel 'systemic' thinking that emphasises holism, complexity, networks and patterns of organisation. They identify eight characteristics of Systems Thinking (2014:80-83), and although each is different, each is characterised by connectedness, relationships and context. The eight are entangled. Nonetheless, it is helpful to examine them individually; especially as these characteristics provide 'warp threads' in the structural framework for the fabric of the current research—anchoring it and endowing it with direction, rationale, purpose and context. The eight characteristics and the relevance to this research are discussed below.

1. Shift of Perspective from the Parts to the Whole...A Holistic Worldview

Capra and Luisi identify the emergence of a new paradigm, a holistic worldview characterised by a shift of metaphors from seeing the world as a machine to seeing the world as a network—seeing the world as an integrated, interconnected whole rather than a dissociated collection of parts (Capra & Luisi 2014:12). Systems Thinking is characterised by the understanding that the essential properties of an integrated whole cannot be reduced to those of its parts; instead, the parts arise from the interactions and relationships between themselves (2014:10). As quantum physics demonstrates and Capra and Luisi observe, there are no parts at all (2014:80), giving rise to the conceptual

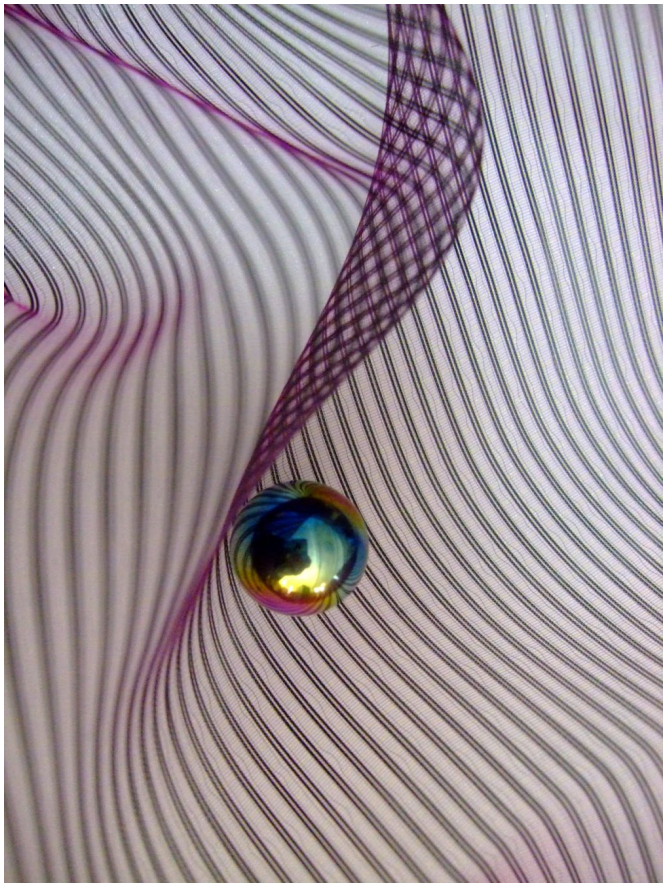

Image 44: Translucent striped fabric, tempered metal marble. 2016

shift from parts to the whole. Bohm also based his theories of implicate and explicate orders of reality on a premise of underlying wholeness, employing notions of unfolding and enfolding; he said, "The parts are not divided from each other, because you can see that underneath they come out of a common whole—unfolding" (Bohm 1985b:27).

The current research creates works that repeatedly examine the relationship between parts and the whole; for example, we do not have an everyday experience of each of the spectrum colours. They are fundamentally tightly enfolded parts of the whole of white light; we only see the individual colours in light if they are optically disentwined. In this enquiry, this is revealed through the use of diffraction grating

2. Inherent Multidisciplinarity...Applied 'Textile Thinking'

Systems Thinking is intrinsically multidisciplinary (Capra & Luisi 2014:80) and can be applied to integrate various academic disciplines by seeking to find similarities between different phenomena rather than highlighting their differences (Capra & Luisi 2014:80). There is a growing trend for an interdisciplinary blending of concepts, formats, disciplines and technologies and there are an increasing number of attempts to name and define it—some of the proposed designations of the post postmodernist era include Post-millennialism, Hypermodernism, Performatism, Syncretism, Digimodernism, Metamodernism and Altermodernism. Another value of interdisciplinarity is that it dislodges discipline boundaries (Sullivan 2010:245). For example, although Karen Barad's primary inspiration for their theories of *agential realism* and *intra-action* derives from their 'diffractive methodology' drawn from Niels Bohr's interpretation of quantum mechanics, they take an interdisciplinary approach, drawing from a range of other fields that include, the philosophy of physics, feminist theory, critical race theory, postcolonial theory and poststructuralist theory (see Chapter 6).

Being positioned at the crossing point of many disciplines, the practice-based approach of the current research incorporates diverse worldviews of the foundations of matter drawing on diverse interdisciplinary sources which permits alternative viewpoints to emerge (Sullivan 2010:117-118). Interdisciplinarity is a process that enables a synthesis—entwining parts to create wholes that can then be used to reshape those parts (Dalke *et al*. in Jefferies 2006:7). However, interdisciplinary practices require a methodology and tools that can manage complexity, multiplicity and interconnectivity—a methodology of textile thinking is ideal for this. With its effective and recognisable metaphors of braiding, weaving, folding and entanglement, textile logic accommodates and manages the complexities and breadth of scope of this holistic and interconnected approach to the research. It can manage complexities, paradoxes and possibilities for non-linear thought and help to anchor the ephemeral themes (see Chapter 4).

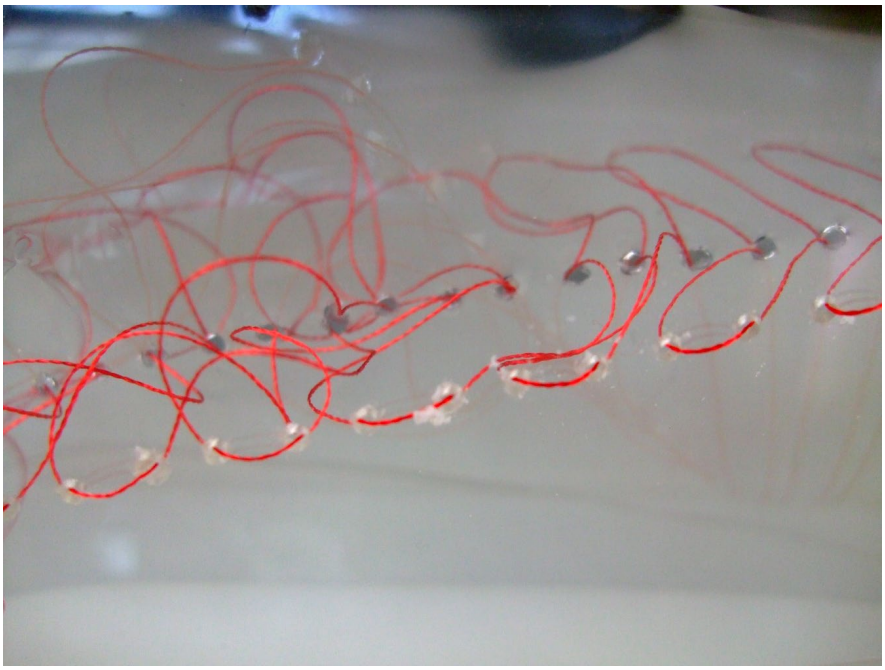

Image 45: Red thread, two-way mirror with drilled holes. 2015.

In response to Bohm's textile metaphors of enfolding and unfolding, the initial stages of the research examined and worked through notions of *the fold* as an emblematic starting point. However, as the investigation progressed, it became clear that there was considerable value in expanding on Bohm's use of textile language by broadening the scope of textile logic through the repeated use and examination of other textile terms (such as weaving, braiding and entanglements) as both motifs and processes.

3. From Objects to Relationships...A Figure/Ground Shift

> What we call a part is merely a pattern in an inseparable web of relationships. Therefore, the shift of perspective from the parts to the whole can also be seen as a shift from objects to relationships (Capra & Luisi 2014:80).

In the mechanistic view, the world is a collection of interacting boundaried objects—the relationship between them is secondary. However, there is a shift in perspective in the Systems View—relationships are primary, and objects are viewed as networks of relationships (which, in turn, form parts of more extensive networks) (Capra & Luisi 2014:80). Through their reading of Niels Bohr's quantum mechanics, Barad has further developed this with their theories of 'intra-action'; they argue that distinct agencies do not precede, but rather emerge or materialise through their intra-action. This is because the ability to act, behave or perform emerges from *within* the relationship and not from outside of it (2007:33). Barad argues that intra-action challenges and reworks traditional ideas of causality, individual agency and subject/object dichotomies, which call determined or fixed borders and boundaries between subjects and objects into question (2007:33).

In addition to challenging subject/object, viewer/viewed dichotomies, many of the series of artworks and the immersive installations explore and question the boundaries of things. For example, the boundaries of the *Indeterminate Interface* series (see Chapter 10) are both contained and not contained at the same time. They are framed and yet extend beyond the frame—questioning the margins and limits of the pieces. They give concrete expression to the crease between the material and the immaterial, suggesting an edge of becoming—the interface between the reality we experience and the mystery underlying all things.

Capra and Luisi characterise the perceptual shift from objects to relationships as a figure/ground shift (2014:80). A figure/ground relationship is one of the principles of the Gestalt psychology of perception and is often employed by artists and designers. One aim in creating the artworks in this research is to question directly the perspective of the primacy of the figure as a device to point to the wholeness that underlies reality. For example, the *Lenticular* works directly express the figure/ground shift—visually flipping between positive or negative states but not prioritising one over another (see Chapter 9).

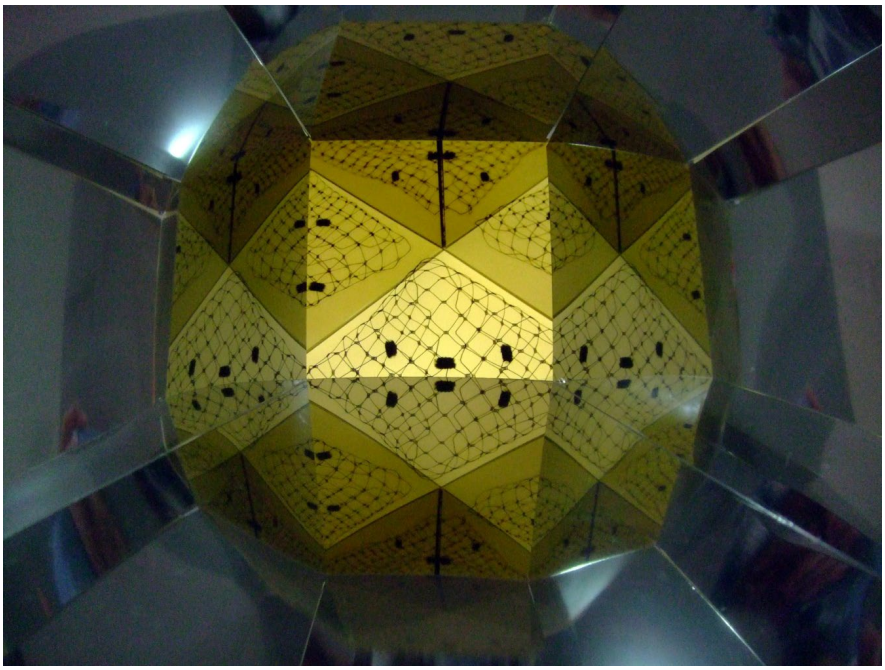

Image 46: Mirror card and photograph of birdcage netting. 2015.

4. From Measuring to Mapping...Finding Correspondences

In Western culture, especially in science, things are categorised, measured and weighed; however, we cannot measure or weigh relationships. This therefore requires a change in methodology. Capra and Luisi state that relationships and interconnections need to be mapped to find recurring configurations and patterns of organisation. For this reason, rather than critiquing other writers and emphasising differences, the current research seeks to find correspondences, correlations and parallels that support and interweave the themes of this research across disciplines of art, quantum physics and philosophy and metaphysics. Equally, Capra and Luisi discuss the similarities between the Systems View and Buddhism and Western mystical traditions (2014:274-296) and observe the growing convergence between various scientific disciplines and spiritual traditions, providing a consistent philosophical background to their contemporary scientific theories (Capra & Luisi 2014:70).

5. From Quantities to Qualities...Art Practice-Based Qualitative Research

Systems Thinking recognises that we cannot understand the nature of our world's complex societal, economic or ecological systems in purely quantitative terms; instead, it is based on qualitative mathematics of complexity theory or non-linear dynamics (2014:81). Capra and Luisi repeatedly emphasise that the Systems View is essentially a science of qualities with a requirement for an appreciation of the role of subjective experience (2014:368-369). They offer the following distinctions (Capra & Luisi 2014:13):

Quantitative	**Qualitative**
rational	intuitive
analysis	synthesis
reductionist	holistic
linear	non-linear

Art practice-based research is fundamentally a qualitative research methodology that is intuitive, holistic and non-linear and is therefore suitable for synthesising and communicating complex ideas (see Chapter 4). In *Art Practice as Research: Inquiry in Visual Arts* (2010:95-188), Graeme Sullivan argues that art practice as research expands on the qualitative methods offered by the social sciences through the open-ended character of art practice that capitalises on imaginative capabilities. Qualitative research methods are holistic as they are interconnected processes covering many different dimensions (Mayoux 2001), making them an appropriate methodology for seeking unity from multiplicity. This is discussed further in the next chapter.

Although the thesis text is a linear form, the research itself is a non-linear process as it unfolds and refolds, bifurcates and loops back on itself. Consequently, the reader will

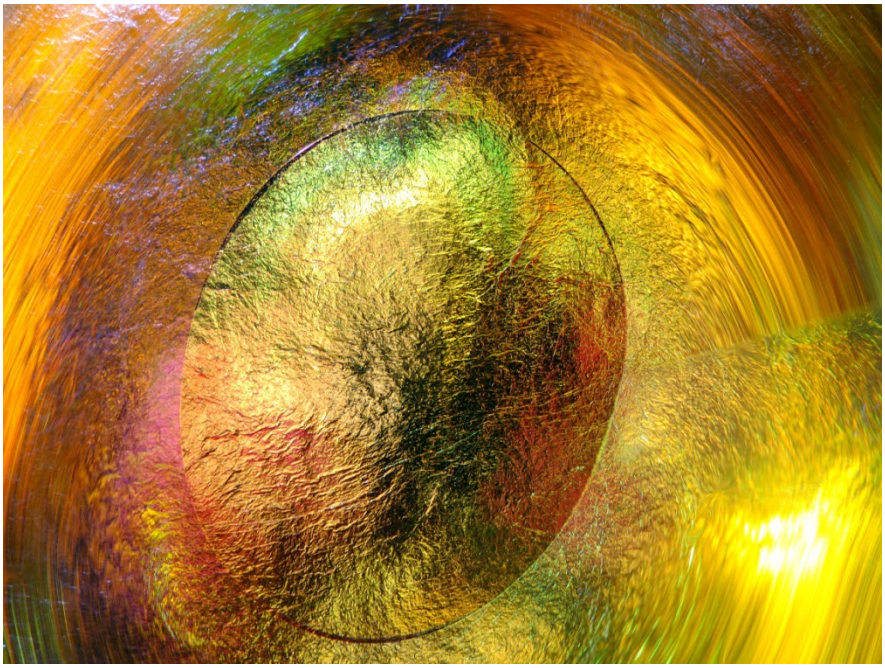

Image 47: Dichroic film, silver leaf on paper, sunlight. 2018.

experience recurring ideas and themes that are repeatedly visited and revisited throughout this thesis and discussions of the artworks.

6. From Structures to Processes...Dynamic Unfoldings

In the Systems View, structures are seen as the manifestation of underlying processes characterised by movement and flow. Physics teaches us that the nature of matter is intrinsically dynamic and that it cannot be separated from activity (Capra & Luisi 2014:75). This corresponds to David Bohm's theories of the implicate/explicate orders of reality (Bohm 1980; 1995; 2000), where the underlying implicate order is an endless process of movement (1980:177). Bohm devised the word *holomovement* (meaning movement of the whole—*holo* from the Greek for whole) to incorporate ideas of movement, flow and flux (1980:150-157). Holomovement was one of his key theories in his interpretation of quantum mechanics, and he posed that it acted as the "fundamental ground of all matter" (Bohm & Peat 2000:180). It is most fully described in his book *Wholeness and the Implicate Order* (1980), where he poses that the universe is like a hologram—everything is enfolded into everything else and the manifestation of all forms, their becoming, is the result of endless enfoldings and unfoldings:

> Not only is everything changing, but all is flux. That is to say, what is the process of becoming itself, while all objects, events, entities, conditions, structures, etc. are forms that can be abstracted from this process (1980:48).

Bohm also used an analogy of vortices and eddies in the flow of a river to describe how regions of order could be contained within the continuous flux, stating, "Flow is in some sense prior to that of the 'things' that can be seen to form and dissolve in this flow" (Bohm 1980:11). Even though a river is in constant movement, the turbulence patterns created by the vortices are relatively stable; although they are separate structures, they are one with the whole river (see Chapter 7).

In response to the theories of holomovement and dynamic processes, although static, many of the artworks for this enquiry suggest movement through their compositions or the illusory effects of the optical materials used such as moiré effects.

Bohm and Peat examined the creative process in *Science, Order and Creativity* (2000), where they discuss the generative order (2000:148-228) which is related to the implicate order. It is a "deeper and more inward order out of which the manifest form of things can emerge creatively" (2000:149). In this research, the artistic process is key—the holistic, non-linear nature of the creative process is akin to the process of Bohm's explicate forms arising from the underlying implicate orders. A creative process is integral to an art practice where there is a translation from intellectual understanding and intuitive feeling to

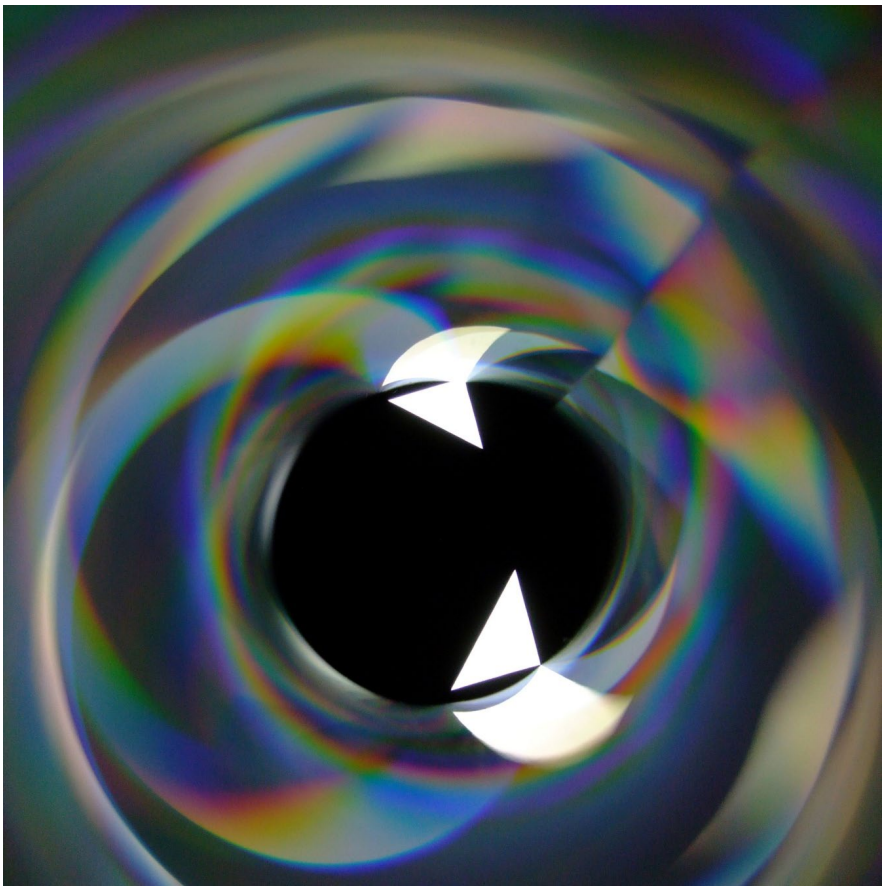

Image 48: Cut black paper, diffraction grating, LED light. 2018.

material forms. An artistic, qualitative methodological approach draws from the whole person, not just through the quantitative processes of analysis, theorising, reflection, critical decision-making and the thinking mind but also through a non-linear dynamic between conscious intentions and mysterious subconscious forces.

In this research, thinking-through-making is a speculative process that allows innovation and an interface with the unknown as there is potential for intuition and mysterious internal subconscious processes. Moreover, as outcomes are not wholly controlled, there are opportunities for chance happenings, 'accidents', synchronicity and coincidences to move the thinking forward in unexpected ways to create new, unanticipated forms and processes or reveal recurring patterns, connections or themes. Although creative processes are difficult to quantify, their results are evident in the artworks that reveal new possibilities and ways of looking. The birth of new forms occurs through a continuum repeated by 'working into' previous outcomes: this in turn, results in more new configurations.

7. From Objective to Epistemic Science...Role of the Observer/Viewer

Descriptions in Cartesian science are required to be objective and independent of the human observer and process of knowing. However, in the Systems View, epistemology has to be included—objects depend on the human observer as well as on the process of knowing, therefore, the method of questioning is integral because different observers question in different ways. This affects the outcome. The 'observer effect' is a key feature of quantum physics; Niels Bohr's theories argue that there is no definite way to distinguish between the observer and the object, and, as Werner Heisenberg remarked, "What we observe is not nature itself, but nature exposed to our method of questioning" (1958:58). Barad remarks that, beyond the absolutism and relativism of Cartesian science being the only two possibilities, quantum physics leads us to consider both "epistemological and ontological issues—issues concerning the nature of knowledge and the nature of being" (2007:18).

The two-slit experiments (see Chapter 4) reveal matter's bizarre properties and behaviours at the quantum level, one of which is the above-mentioned 'observer effect'. The experiment's outcome depends on whether or not the experimenters are detecting which of the two slits the photon or electron passes through—it either behaves as a wave if it is not observed or acts as a particle when watched. It is as if the particle 'knows' whether it is being observed or not (Pylkkänen 2010:165) demonstrating that there is an inextricable connection between the observer and the observed.

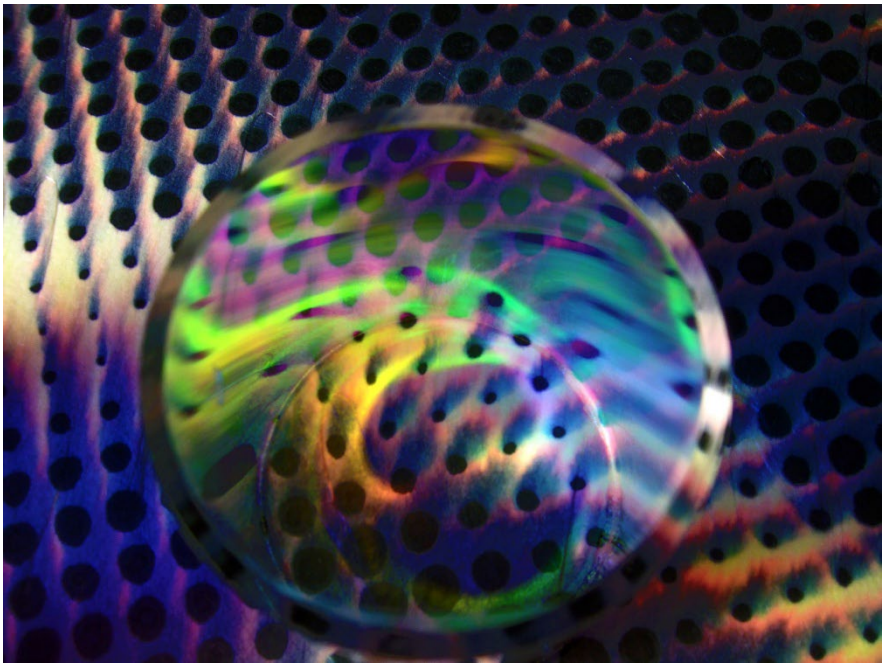

Image 49: Black ink drawing, dichroic film, acrylic tube. 2018.

Based on Bohr's theories that there is no definite way to distinguish between the observer and the object, Barad summarises that the two-slit experiments demonstrate the mysterious way that the experimenter/apparatus, subject/object are entangled and reiterates that there can be no such thing as a detached observer (2007:14). Correspondingly, the actions of the viewers are crucial to the experience of artworks and installations, such as the *Quantum Questions—Line Interrupted* series and the Lenticular series. They activate the work by receiving different information from different angles of the artwork as they move position.

Although all possible views exist within the work at all times, the viewer's position can only be in direct relationship with one specific view at one time—another viewer has a different viewpoint and sees something different. For example, when each is looking at the same artwork, one viewer may see a riot of colour, the other only black and white. As with many of the artworks for this research, our expectations of fixedness and defined borders that separate things are challenged; the shift is from an assertoric gaze to an alethic gaze, offering a new mode of looking that introduces possibilities for new more open ways of thinking. Philosopher David Michael Levine (later known as David Michael Kleinberg-Levin) defined two modes of vision: firstly the 'assertoric gaze', which he characterises as narrow, dogmatic, intolerant, rigid, fixed, inflexible, exclusionary and, secondly, the 'alethic gaze' which sees from a multiplicity of standpoints and perspectives and is pluralistic, democratic, contextual, inclusionary, horizontal and caring (Pallasmaa 2005:36; Levine 1988:440).

8. From Cartesian Certainty to Approximate Knowledge...Questioning Certainty

Contrary to the Cartesian belief in the certainty of 'objective' scientific knowledge, Systems Thinking recognises that all scientific concepts and theories are limited and approximate, so science can never provide a complete and definitive understanding. Nonetheless, Capra and Luisi observe that approximate models and theories to describe the "endless web of interconnected phenomena" are nevertheless effective and can be improved over time (2014:82).

Quantum physics has had to resolve the issues of uncertainty and indeterminacy and has interpreted the dual nature of quantum wave/particles in different ways (see Chapter 5). Heisenberg's uncertainty principle (also known as the indeterminacy principle) proposes that there is a limit to what we can simultaneously know about specific pairs of physical quantities.

Heisenberg theorised that the not knowing is not because the apparatus, technique, or the observer are inadequate; rather, that it arises from the relationship between quantum

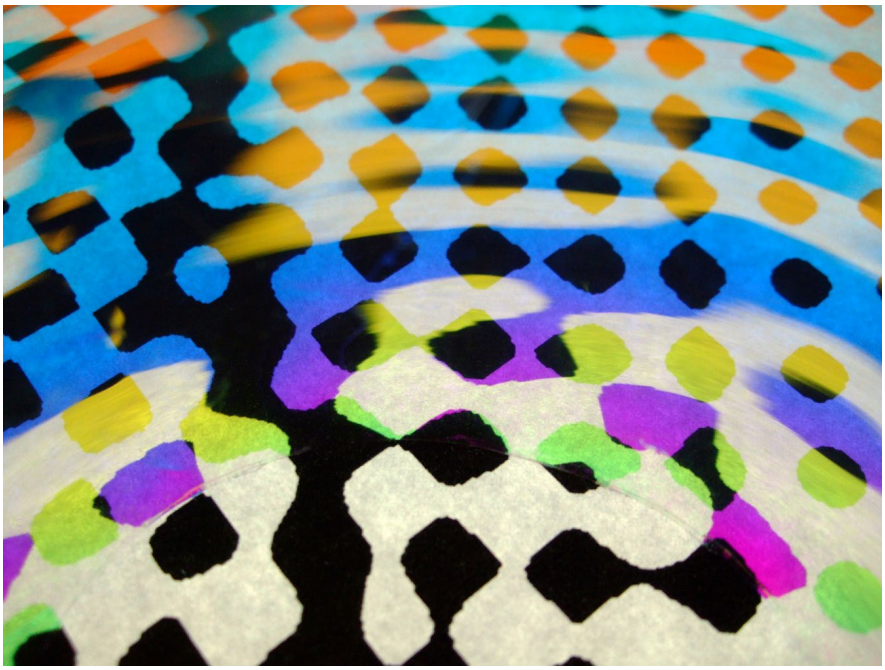

Image 50: Black ink print, dichroic film. 2017.

particles, waves and the apparatus. On the other hand, Bohr takes a different view; his complementarity framework says that it is not what we *know* about both the position and momentum of a particle simultaneously but that particles do not *have* determinate values of position and momentum simultaneously. In Bohr's complementarity, either particle or wave becomes the determinate property and the other 'complementary' property remains indeterminate depending on the apparatus used (Wilkins 1987:338-360). This questions Western metaphysics' historical belief that the world is made of individual things with their own independent sets of determinate properties.

A key feature of the artworks is that they repeatedly question certainty and constancy. Due to the illusory nature of the materials used, the viewers' experience is not fixed, and they are often uncertain as to what they are looking at—shapes, colours, space and positions of elements shift and are not fixed. That very uncertainty actively questions the viewers' perceptions, acting directly on the perceptual apparatus of the Reticular Activating System (RAS) in the brain so that the artworks offer a site for a shift in perception by loosening fixed beliefs, especially those based on a mechanistic and fragmented worldview.

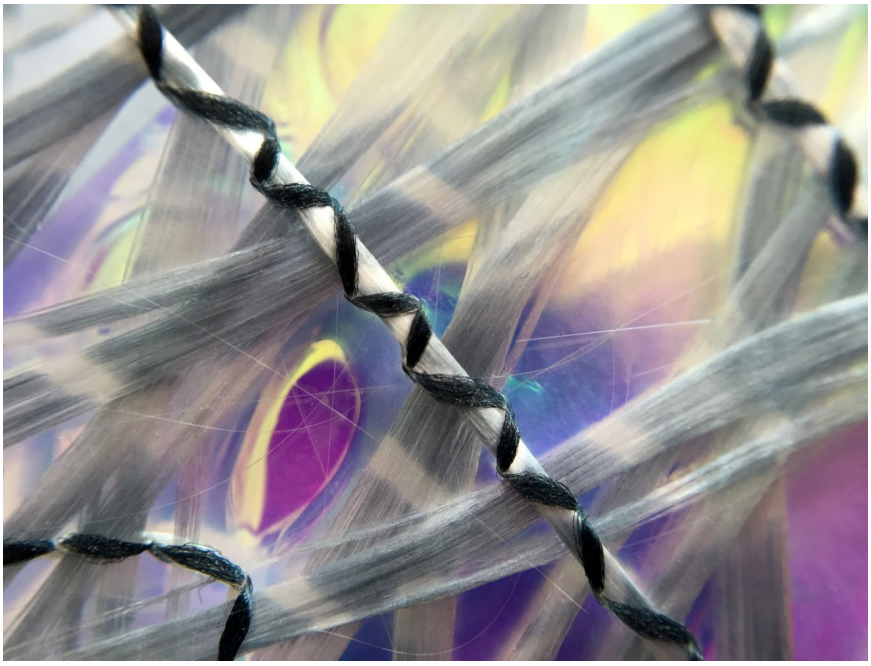

Image 51: Printed tri-axial fabric, embossed dichroic film. 2016.

Part II—Methodology

Chapter 4
Braided—Art Practice as Research and Soft Textile Thinking

Textile Notion #3: Braiding

A braid is a complex but unified structure created by plaiting together three or more threads, ribbons or strings into bands of varying widths.

Metaphorically, braiding is often used to interweave dichotomous, differing and complex ideas to create a unified whole. It offers unifying ways of thinking and is an appropriate metaphor for managing complexity—there is an etymological connection between 'braid' and 'complexity'. Braid stems from the old English *bregdan* (c. 1200) meaning join together, bend, weave, knit, change colour, and vary (Online Etymology Dictionary). Complex derives from the Latin, *plexus* (the past participle of *plectere*), meaning to weave, entwine or braid—the prefix 'com' from *cum* means in combination—meaning braiding together (Gell-Man 2002:17).

Tim Ingold compares life to a plaited braid, writing, "In the braid, each and every strand is equivalent to the record of a life, of its doings and undergoings. However tightly it is bound with others, it retains its own particularity" (2022:265; 2022:317).

Introduction

Light is a threshold phenomenon that straddles the immaterial and the material. This enquiry aims to express phenomena ensuing from the pursuit of an understanding of quantum light that are usually difficult to communicate. It is positioned at the crossing point of many disciplines and draws together many themes so that the methodology, literature, concepts, art-making and outcomes are all entangled and intertwined. As a result, the boundaries between the methodology and a discussion of some of the contextual literature are indeterminate as they are interwoven and are discussed simultaneously.

As seen in the first chapter, an interrogation of edges, interfaces and thresholds at the edges of becoming is key to this enquiry. Graeham Sullivan observes that although the "conceptual edges help to define areas of interest" of the general methodology of a visual

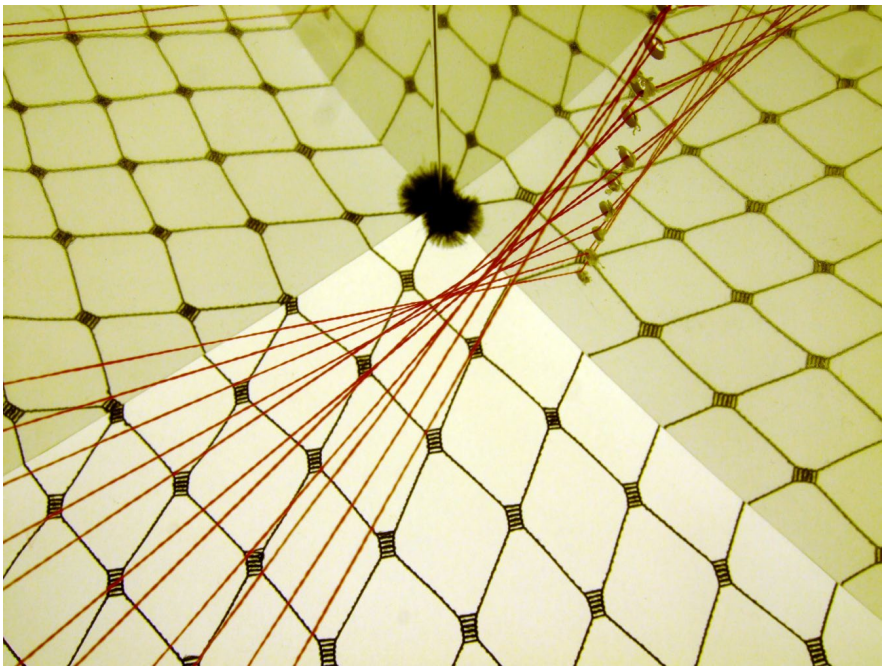

Image 52: Mirror with drilled holes, birdcage netting, red thread. 2015.

arts framework, "they are permeable barriers that allow ideas to flow back and forth". He continues that it is a structure that is "constantly unfolding in a braid-like manner during the research process" (2010:100-101). His use of the textile term braiding here points to applying a textile thinking methodology to this enquiry. More generally, textile thinking accommodates the breadth of scope and a holistic and interconnected approach to the research topics.

Textiles provide a universal tacit experience of non-linearity, non-duality and wholeness, so that concepts can be communicated through a shared and embodied material language and awareness. Because our shared understanding of them extends beyond what can be expressed through words, in this research, textiles serve to materialise and anchor the immaterial and abstract; "the knowledge of practitioners can illuminate the abstractions of historians and theorists" (Pajaczkowska 2016:92). They can be used to question dualisms emerging from a study of light; for example, in her textile practice-based PhD, Kay Sheila Lawrence (2014) deliberately employs textile language to disrupt dualisms. She engages materials and applies metaphors of weaving, embroidery, knitting and binding across her studio practice, interconnecting threads that "break the binary opposition of patriarchal dualism" and "contribute to nullifying Cartesian dualisms of culture/nature oppositions" (2014:2). These align with Capra's Systems' Thinking characteristics 7 and 8 (see Chapter 3).

Methodology—Arts-Based Research

Along with textile thinking, an arts-based research framework offers a trans-disciplinary, transformative research methodology (Sullivan 2010:110-120) that is ideally suited to the nature of this enquiry. As the matters arising from the science of light under consideration are complex, the form of the enquiry requires a flexible and hybrid methodological strategy that is not constrained by disciplinary rigidities which an arts-based research methodology offers. There is a diverse toolbox of arts-based research methods available to researchers (Barone & Eisner 2012:170), which allows the possibility of drawing simultaneously from a variety of viewpoints (Haywood Rolling 2013:70), namely, art, science (classical and quantum) and philosophy (Eastern as well as Western).

Arts-based research is generally considered to be qualitative research and definitions are still evolving. Nonetheless, it can take place and offer alternative viewpoints within and beyond traditional discipline boundaries (Sullivan 2010:117-8) and is particularly suitable for this research project which does not fit neatly into clearly defined research frameworks. The eclectic approach draws on interdisciplinary sources and borrows from interpretivist, empiricist and critical practices, as defined by Sullivan in *Art Practice as Research:*

Image 53: Canvas, cut lenticular photographs, black thread. 2021.

Enquiry in Visual Arts (2010:95-188). Sullivan argues that, as the open-ended character of art practice as research capitalises on imaginative capabilities, it expands on the qualitative methods offered by the social sciences. The value of qualitative research methods in contributing to a shift in perception is elucidated in the fifth characteristic of Capra and Luisi's Systems Thinking (2014:81) (see Chapter 3).

Egon and Guba (1994:104-117) identify four competing paradigms in qualitative research: Positivism, Post Positivism, Critical Theory and Constructivism; however, they argue that arts-based research does not fit neatly into these research paradigms. James Haywood Rolling ventures further, stating that arts-based research is, in itself, a legitimate research paradigm. Conrad and Beck (2015) concur and, in examining the case for art-based research to be a valid paradigm, they state, "arts-based research should not be seen as a scientific activity, but a vigorous, partly intuitive, process for meaning-making in its own right" (2015:17).

Identifying ten essential qualities of arts-based research (2012:164-172), Barone and Eisner note that arts-based research adds to, but does not replace, earlier research methods (2012:170). Firstly, they maintain that there are a myriad of forms of representation for understanding the world, each producing a distinct view. They acknowledge that arts-based research is inherently qualitative and note that qualitative experience is gained through sensory information, which is more subjective and therefore more able to capture meanings that quantitative methods cannot. In addition to rationality, other ways of knowing that are open to an artist-researcher might include sense perception, tacit knowledge, emotion, intuition and imagination (2012:168). However, Haywood Rolling holds that art-based research allows for both quantitative methodologies (typically appropriate for scientific research) and qualitative methodologies (usually more fitting for social science research) to be available to the arts-based researcher. He states that using the methods of one does not exclude the other,

> thereby extending the array of questions researchers may address and the methods or terms they may use to explain them—enriching the gene pool of knowledge *in terms of differences in ways of knowing* (Haywood Rolling 2013:8) [his italics].

The current research attests to this, as, although it should be characterised as primarily qualitative, it utilises quasi-scientific experimental methods in its material investigations by systematically examining the nature and behaviours of light and optical materials more commonly used in a laboratory (see Chapter 8).

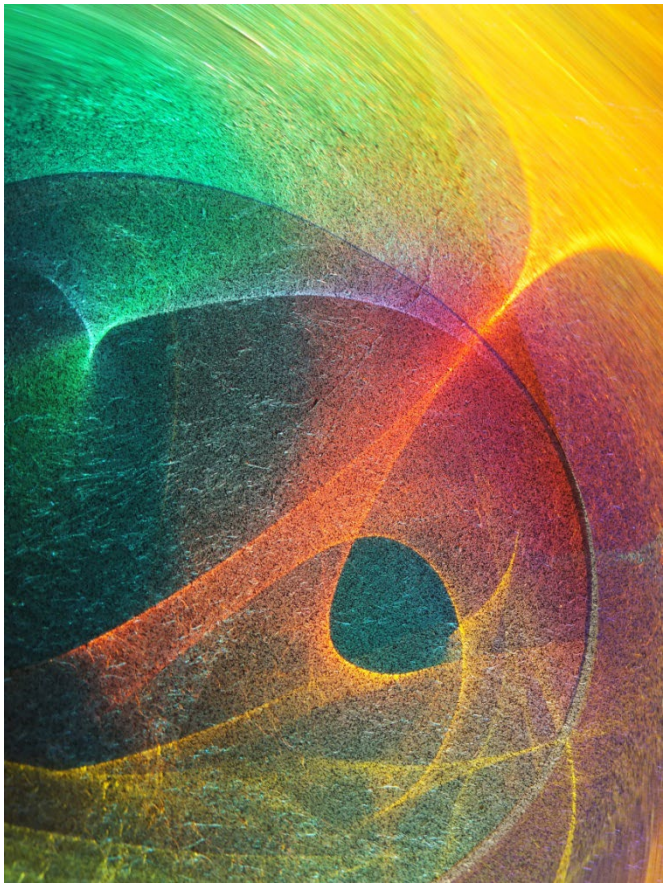

Image 54: Dichroic film, silver leaf on textured paper, sunlight. 2018.

Importantly for this enquiry, Haywood Rolling argues that arts-based research privileges the inclusive nature of a 'both/and' hybridity of both quantitative and qualitative methodologies over the more polarising binary of a traditional 'either/or' approach (2013:70). This inclusive approach is key here, particularly in creating the artworks that synthesise many (often opposing) elements. As an example, as well as being of conceptual concern, the intention to question dualisms is evident in the methods and materials used in the artworks by folding together opposing qualities such as interior/exterior, hard/soft, virtual/real, parts/whole and colours with their complementary opposite (see Part IV for how this applies to the art practice).

Aligning with the eighth characteristic of Capra and Luisi's Systems Thinking, questioning certainty (2014:82), Barone and Eisner argue that a valuable outcome of arts-based research is to raise questions and open conversations rather than provide conclusive meanings, explaining, "By arts-based research, we are more interested in puzzlements than certitudes" (2012:172). Similarly, the arts-based research paradigm that Haywood Rolling proposes offers a "*proliferation of alternative ways of knowing* over the *proving of certainties* [his italics]" (2013:12). Likewise, the outcomes of the current enquiry contribute fresh angles and open up possibilities for new questions rather than producing absolute answers by presenting new visual forms to the existing body of knowledge.

Any perspective on the world is always partial and has its limitations (Barone & Eisner 2012:168); however, as Capra and Luisi observe in the first characteristic above, the parts are never separate from the whole (2014:80). An interdisciplinary approach is holistic in character (Mayoux 2001). As the study of light questions separation and wholeness (see Part III), discussions of parts and the whole thread throughout this thesis.

Reality and the state of knowledge are complex and constantly in flux; however, an art practice permits simultaneous multiple realities which is apt for researching the paradoxes presented by quantum discoveries of light. Two methodological frameworks for art practice as research that not only manages complexity but also support and contextualise the methods used in this research and offers guidelines for crossing methodological boundaries and creating multi-genre representations are discussed below. Firstly, *A/r/tography,* a fusion of art, research and teaching, and secondly, *Crystallisation*, which is commonly used by researchers who employ mixed-genre texts.

A/r/tography

A/r/tography*,* theorised by Rita Irwin and Stephanie Springgay, draws on scholarship from various disciplines (including philosophy, phenomenology and feminist theories). It views

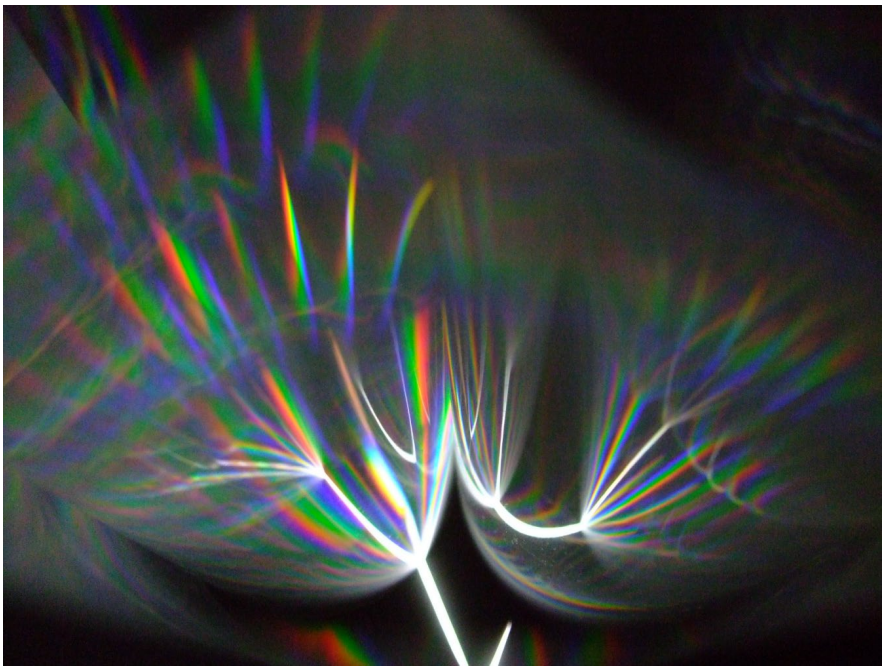

Image 55. Cut black paper, dichroic film, LED light. 2015.

knowledge production as difference, thereby tendering different ways of being. It blends grounded theory with creative representations of data such as narrative, poetry and film, "A/r/tographical research is not subject to standardized criteria, rather it remains dynamic, fluid, and in constant motion" (2007:xix). Building on Deleuze and Guattari's concept of the rhizome (2013), they intertwine theory, doing and making, stating that, "All three ways of understanding experience—theoria, praxis, and poiesis—are folded together and form rhizomatic ways of experiencing the world" (Springgay *et al*. 2008:xxiv). The application of this is discussed in Chapter 8.

Combining theory with looking, doing and making is key to the approach in this project; each of these activities leads to and blends with another—they are entangled and the distinctions between them are often unclear. It is challenging to unbraid them and tease the strands apart to examine them linearly for the text of this thesis. Fortunately, however, these elements are comfortably incorporated within the artworks where the braided nature and indeterminate boundaries between things are not only permitted but are also key features and intentions. In A/r/tography, there is an emphasis on the in-between where meanings reside simultaneously in language, images, materials, situations, space and time—the artworks for this research demonstrate that indeterminate boundaries and the in-between are conditions that disrupts dualisms. One of the principles of A/r/tography is to disrupt the art/science dichotomy within the academic arena (Ellingson 2009:16; 2007:xx) which is a recurring feature within this research where art and scientific theories are entwined with optical materials.

Crystallisation

The second methodology, *Crystallisation*, supports the complexities of knowledge production and also questions dualisms, including art and science (2009:34). Instead of posing one against the other, Laura L. Ellingson describes the art/science methodological approaches as existing on a continuum in *Engaging Crystallization in Qualitative Research*. She writes,

> Crystallization necessitates seeing the field of methodology not as an art/science dichotomy but as existing along a continuum from positivism (i.e. scientific research that claims objectivity) through radical interpretivism (i.e. scholarship as art). Art and science do not oppose one another; they anchor ends of a continuum of methodology, and most of us situate ourselves somewhere in the vast middle ground (2009:5).

Crystallisation crosses methodological boundaries enabling a blending of artistic, interpretive and creative activities with critical approaches to research, allowing the researchers to combine multiple forms of analysis and representation to represent multiple

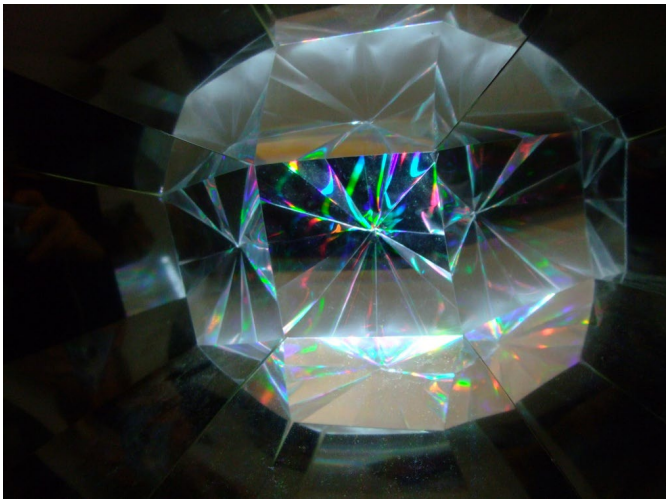

Image 56: Mirror card, diffraction grating, mapped projection, white light. 2016.

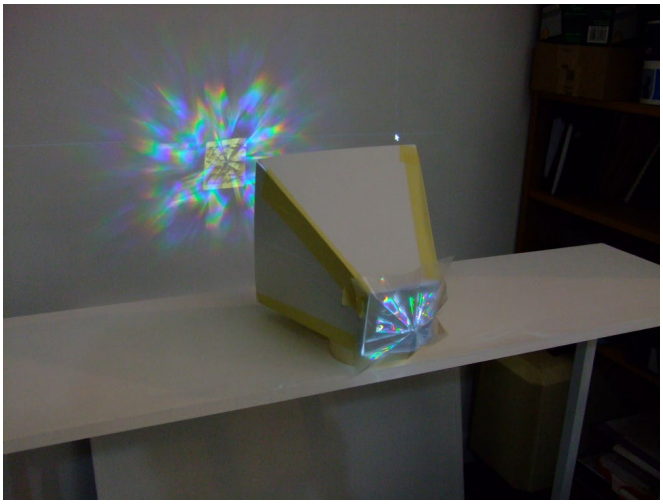

Image 57: Mirror card, diffraction grating, mapped projection, white light. 2016.

perspectives of a phenomenon. The metaphor of the many-faceted crystal is helpful but has its limitations so Ellingson supplements it by introducing three textile metaphors—quilting, weaving (2009:104) and patch working (2009:111). She uses quilting as an interrogative tool and strategy for merging genres and representations and "as a heuristic for imagining the process of bringing genres together" (2009:97). She sees weaving as a process of combining small parts together; however, this is more akin to patch-working where small pieces of cloth are joined to create complex patterns to form single whole fabrics. This fits with Ellingson's purpose of piecing together different styles of texts to give a variety of voices that reflect contrasting ways of knowing. However, more accurately, weaving is an activity that primarily unifies dualities; the integration of the warp and the weft—the horizontal and the vertical—to create an integrated mesh of interconnected strands. This definition aligns with the intention of this research—to seek wholeness and produce coherent visual forms expressing complex abstract ideas, making connections and relationships and seeking to highlight correspondences across genres. The metaphor of a whole cloth woven from many threads is appropriate to this enquiry.

Braiding

Both weaving and braiding draw on textile logic and are metaphors for ravelling divergent threads into a unified whole and are threaded throughout this text. Sullivan (2010) suggests that a braided metaphor is appropriate for arts-based research as it enables the intertwining of complexity and self-similarity (concepts he borrows from science and mathematics). He states,

> the braid, with its infolding and unfurling form that disengages and reconnects with core themes while continually moving into new spaces, serves as a useful metaphor that captures the dynamic complexity and simplicity of art practice as research (2010:112).

As an example of applied textile thinking, Bradley Quinn, in his essay 'Textiles and Architecture', describes the inventive potential of applying braiding to architecture to create radically new building forms that alter traditional internal/external relationships (2016). He writes, "By dislocating the structure's core and inverting its contents, braiding eliminates the void by making all spaces visible in a single view" (2016:53).

Braiding is one example of nine types of textile strategies identified by Claire Pajaczkowska who states that knowledge of materials and techniques can make up a conceptual toolbox for the "transformation of thinking" (2016:83). As well as promoting the cultural agency of textiles, she explores the relationship between techniques of making and types of tacit knowledge, offering a useful "toolbox of tropes" which include: felting, spinning, stitching, draping or folding, knotting and weaving (2016:83). She describes

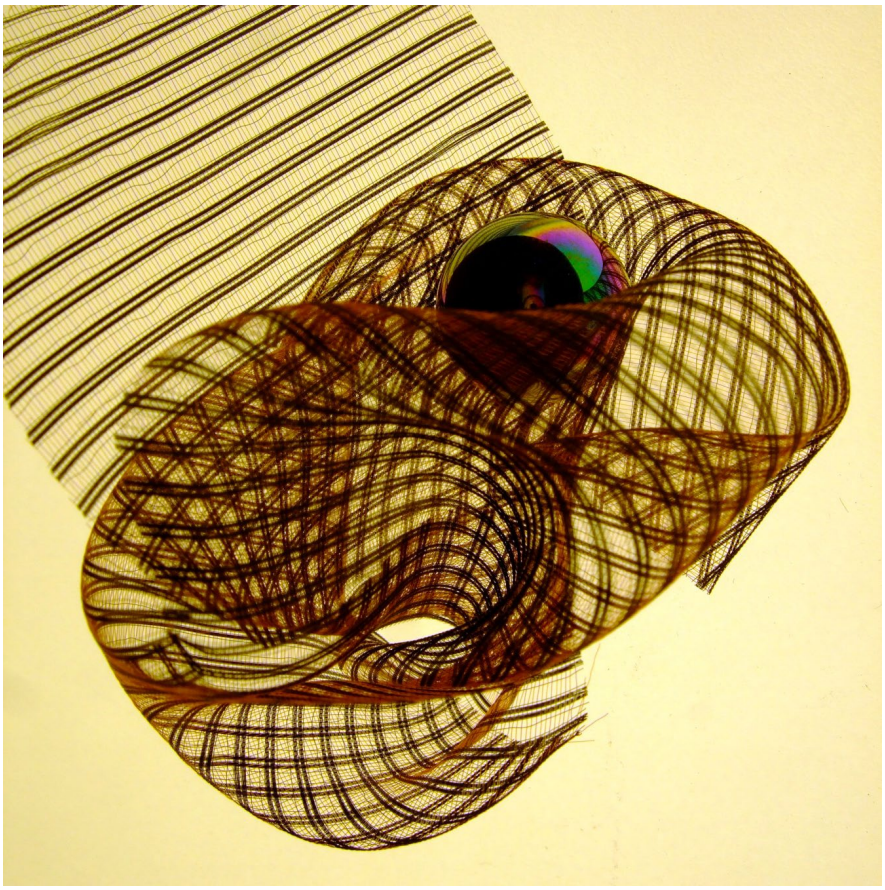

Image 58: Striped translucent fabric, black marble, LED light. 2018.

different material, structural and functional attributes for each trope and making process that contribute to "soft logics".

Applied Textile Thinking

The application of textile logics takes many forms in informing ways of thinking beyond the field of textiles. Textile construction processes such as spinning, weaving, felting, knitting and braiding contribute to a textile logic, as do their structures (in terms of the different ways the fibres are combined to create a unified surface and influence the fabric's qualities and performance). Textiles' performative qualities include, folding or draping, covering and acting as a boundary. Lesley Millar writes that textiles are carriers of emotion and memory because traces of our relationships with cloth permeate its very fibres (2012:11-15; 2014:34); also, across the world and throughout history, textiles have been used as signifiers of identity and status. There is a strong relationship between the words textiles and text, both stemming from a common Latin root, *texere* to weave and several theorists and practitioners have researched the relationship between the two (Jeffries 2016:100, McGuinness 2016:153; Igoe 2013:8). As textiles are multivalent, there is an abundance of available potent textile metaphors (Gordon 2011:23); the metaphorical language of textiles is of primary importance to this enquiry.

Science—Textile Metaphors

Many textile metaphors are employed in many fields including science to convey difficult ideas; for example, 'spacetime-as-textile' exists throughout popular physics discourse (Ancheta 2016). In his book, *The Fabric of the Cosmos: Space, Time, and the Texture of Reality* (2004), Brian Greene uses the spacetime-as-fabric metaphor to discuss both cosmology and quantum mechanics. American physicist, Sheldon Lee Glashow, describes dimensions beyond perception as crumpled (see below for Serres' crumpled handkerchief metaphor for time). Glashow also uses tapestry as a metaphor and entitled his Nobel Lecture, *Towards a Unified Theory—Threads in a Tapestry,* describing developments in theoretical particle physics as moving from being like a patchwork quilt to becoming more like a tapestry where the threads are 'over-woven', so that parts are unified to become a whole (1979). Other common textile metaphors used in science include quantum *loop* gravity, *string* theory and *spin*.

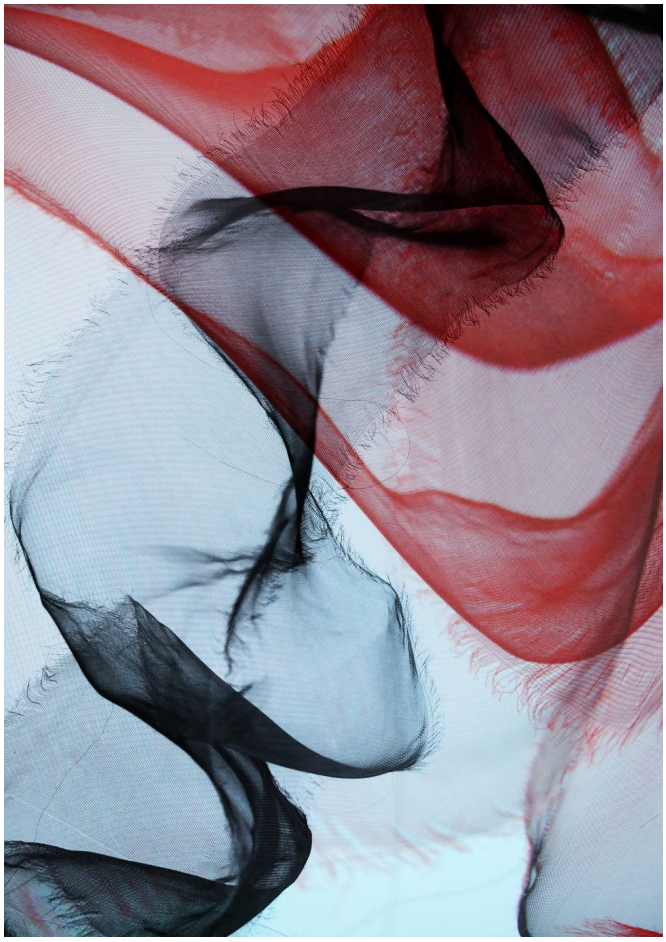

Image 59: Organza folds. 2016.

Textile Notion #4: Spinning

The action of spinning is the process of drawing out and twisting fibres to make thread: spun threads have twist and direction and are stronger when spun together than they are when they are apart.

In physics, spin is a process of electrons and the dynamic element of an atom—a twisting in space that also has direction. Spin is used in many ways; for example, the results of experiments on entangled particles are determined by the instantaneous relationship of changes in spin direction between entangled particles—no matter how far apart they are.

Hardness and Softness

A characteristic of textiles is that they are soft and pliable. In *Atlas*, philosopher, Michel Serres describes cloth as a transitional and unifying material, "neither liquid nor solid, to be sure, but participating in both conditions. Pliable, tearable, stretchable...topological" (cited in Connor 2002). As a way of thinking, Serres, recognises cloth as a highly effective, fluid metaphor for epistemology (2008:81). He writes, "I am seeking the best model for a theory of knowledge, less solid than a solid, almost as fluid as a liquid, hard and soft: fabric" (2008:81).

Soft textile logic is a mode of thinking that several different theorists have employed to concretise and contemplate puzzling or complex ideas, even 'hard' philosophical questions about the nature of reality. In this enquiry, 'hard' questions arise through exploring light's quantum questions and the relationship between the material and the immaterial aspects of reality—the edge of becoming. Serres also folded the material and the immaterial together (2008:85-151). Steven Connor (2009) summarises Serres' metaphorical system of the hard and the soft as a continuum that paradoxically folds back on itself. He writes that it "replaces the traditional separation of material and immaterial with a system focusing on the maximally and minimally material," explaining that, for Serres, the immaterial is to be seen as a softer form of the material (2009). Serres wrote, "Hardness in softness and softness in hardness, a transitional threshold" (2008:129) and used the hard and the soft to examine many dichotomies, including what he terms 'mixed bodies', i.e. the relationship between subject and object. The relationship of subject and object is key to the current research; however, this is drawn from quantum physics, and is examined further in Chapter 6.

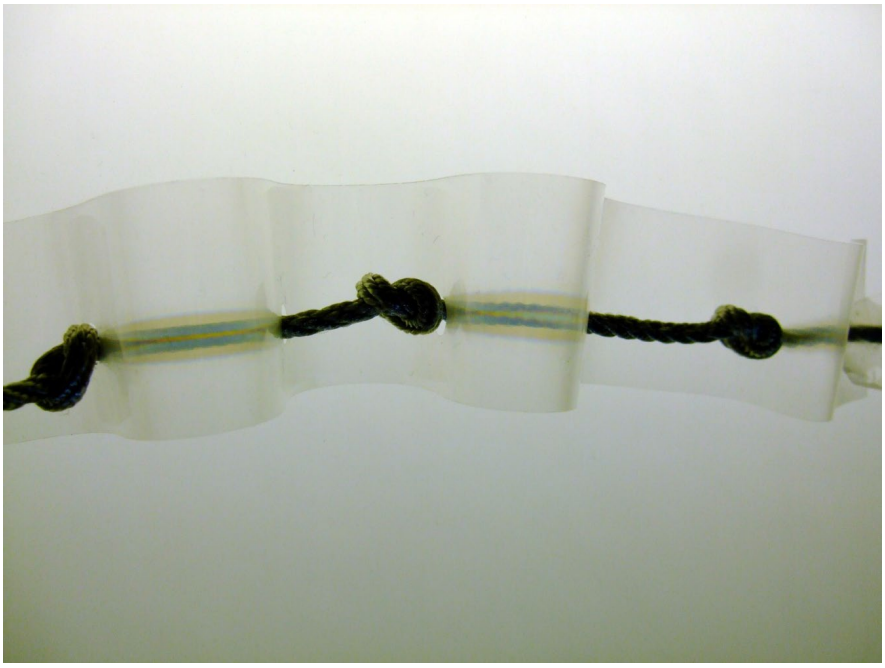

Image 60: Knotted cord, diffraction grating, LED light. 2019.

Tim Ingold coined the term *textility* in '*The textility of making* (2010b) and often incorporates textile thinking into his writings on materials. He diffractively reads one thing alongside a textile trope, comparing and entwining the characteristics of each; for example, blocks and knots (2013b), the braid and the stack (2022:317) and writing and weaving (2022:200-203). The associations created introduce new meanings. He writes on *meshworks* (a term he borrows from Henri Lefbvre) in *Bringing Things to Life: Creative Entanglements in a World of Materials* (2010a); he sets *meshworks* against *atmosphere*, asking whether the environment is a meshwork or an atmosphere, or even both (2022:51).

Applying Soft Logics: Architecture

Textile thinking has applications in a growing number of fields. For example, recently, new architectural models have emerged as architects have embraced textile tropes such as folding, pleating, weaving and braiding to develop new thinking within their field (Quinn, 2016:52). Pliability is a fundamental soft property of textiles that allows them to be manipulated to create three-dimensional space and volume from two-dimensional materials. Historically, architectural practice is profoundly informed by the planar (two-dimensional plane). However, shaped textiles enable a shift from two to three-dimensions to generate new forms and solutions. In seeking a rethinking of "rectilinear logics" to challenge design paradigms toward making space more performative, architects Mette Ramsgaard Thomsen and Karin Bech considered the structural properties of fabrics and developed means of transferring these to architectural contexts (2011:15) as documented in their study, *Textile Logic for a soft space*. They specifically sought solutions that are soft rather than hard and performative rather than static (2011:7). Textile thinking provided a "new material logic" that served architectural methods of production (2011:21). For example, by closely examining the structural properties of felting, they aimed to "invent new tectonic principles informed by the inherent material tensions that are the core of textile structures" (2011:7). They asked, "Are there ways in which the materially performing, the tensile and the friction-based can become part of architectural, structural thinking?" They observed that felted structures are held together by friction and devised practical structural principles for friction-based architecture (2011:22).

Folding

In this project, folding is useful both metaphorically and practically through images of folds in cloth and other materials and through the use of mirrors where, for example in the *Unfolding Light and Space* series, the reflective properties of light create origami-like reflections (see Chapters 5 and 9).

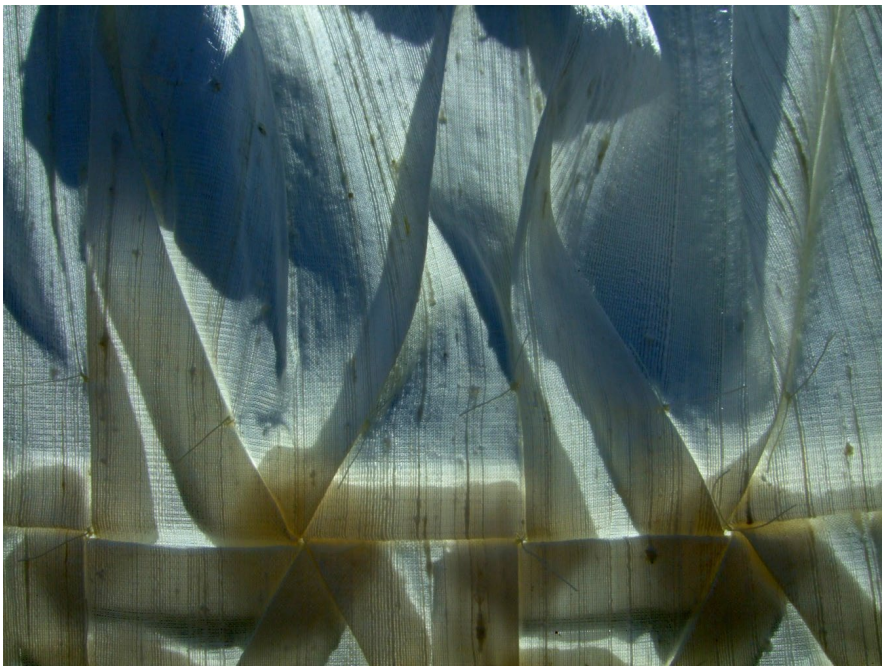

Image 61: Folded silk, sunlight. 2015.

Textile Notion #5: Folding

Folding provides an alternative and concrete way of understanding non-linearity.

Fold: to lay one part over another, entwine, clasp together, and incorporate closely. To bend, to pleat, to crease.
Enfold: to surround, envelop, to form into folds. **Unfold:** to open the folds of, spread or straighten out, to open to the view, reveal, develop and evolve.

In a significant essay, Pennina Barnett (1999) explores textile thinking, presenting folding as "a metaphor for expansive thinking and multiple possibilities" and cloth as an "alternative way of 'soft' thinking, challenging binary structures and their limiting categories" (cited in Hemmings 1999:182). Folding is a frequently used textile metaphor for non-linearity—the relationships between points and spaces alter as cloth is folded and refolded, making it essentially non-linear. However, writer and researcher Alan Kirby argues that 'non-linear' is a confused terminology that is often mistaken for non-chronology and questions of consecutiveness, and he suggests that it is commonly used in this way because it is less oppressive and less restrained than a line, offering more freedom (Kirby 2009:63). Nonetheless, folding and associated metaphors provide alternative and concrete ways of understanding non-linearity, thereby offering creative possibilities.

Folding—Michel Serres

Referencing scientific chaos and complexity theories, Serres uses the image and physical characteristics of "a crumpled handkerchief" to examine the folded, non-linear dynamics of time. In his metaphor, the proximity and relations between Cartesian perpendicular coordinates or points pencilled onto a handkerchief alter topologically when the handkerchief is crumpled or torn. Similarly, time is "gathered together, with multiple pleats...two different points are suddenly close, even superimposed" (cited in Latour 1995:57-60). In this way, the fold is a metaphor for connected multiplicity*, s*omething Serres repeatedly examines in his writings, even stating that his book *Genesis* (1995) is a "meditation on pure multiplicity" (1995:7). He blends scientific discourse with philosophical contemplations and reads multiplicity and the emergence of physical forms through furious 'noise', which he believes is the background to physical forms, life and thought. There are many parallels between Serres' background noise and David Bohm's quiet, dynamic unfoldings of the implicate order (see below)—both produce the material world.

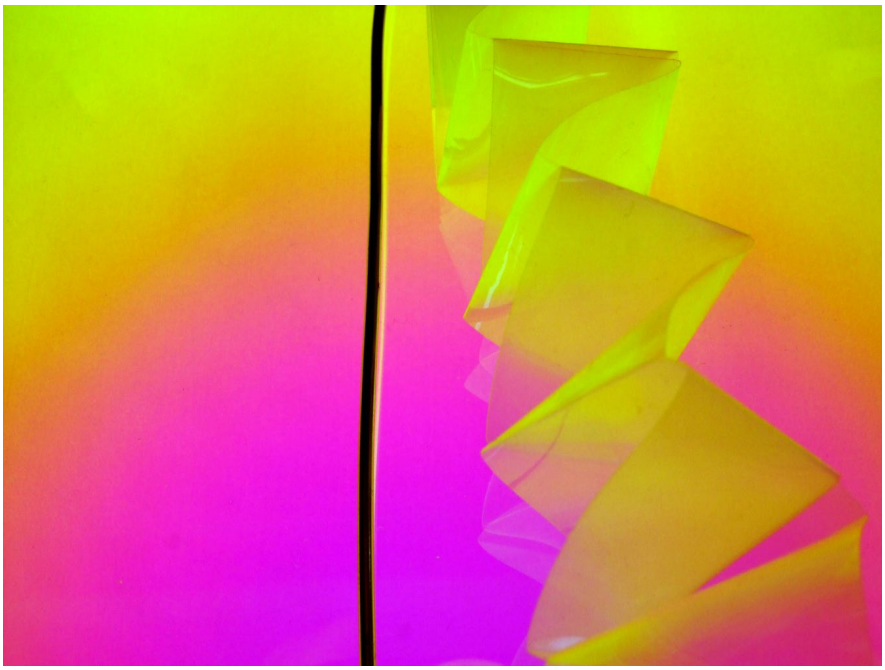

Image 62: Dichroic film, diffraction grating, wire, LED light. 2019.

Folding—Deleuze

Deleuze defines the baroque as the fold that goes out to infinity, and in his seminal work*,* *The Fold: Leibniz and the Baroque* (a frequently cited text), he presents a relationship between the "pleats of matter" and the "fold of the soul" through the allegory of a two-storey house (2006:3). He examines the world, philosophy and art through the motif of the fold by braiding together notions of the baroque with Leibniz's writings whilst exploring ideas of monads, multiplicity and folded continuums. For Deleuze, the fold is a connecting form, a continuity of the interior and the exterior, where even the 'unfold' is simply the continuance of the fold (1991:231). He views numerous aspects of the world through the notion of the fold, including the human body and soul, architecture and the elements—"Folds of the winds, of water, of fire and the earth" (1991:231).

Folding—David Bohm (see also Chapter 7)

Bohm employed analogies of enfolding and unfolding to conceptualise and concretise his theories of the implicate/explicate orders that theorise the nature of reality (Bohm, 1980, 1995, 2010). He asked why the multidimensional medium of space (the vacuum, plenum or void) is capable of unfolding the myriad forms that we sense and experience (1985b:8). To answer this, he developed the theory of the implicate (enfolded) order, which is a deeper and more fundamental order of reality that underlies the explicate (unfolded) order of reality.

Bohm reminds us that the syllable 'pli' in the words im*plic*ate and ex*plic*ate is from the Latin root meaning fold (Bohm 1980:149). Bohm's term, the enfolded implicate order goes beyond the notion of the non-linear—it is a non-local interconnectedness where all matter is connected beneath the quantum level beyond everything we can experience, i.e. the discrete forms that emerge and perpetuate, which he termed as the explicate, unfolded, order.

Folding—Laura U. Marks

Bohm's theories of enfolding/unfolding have been a foundation for other writers and theorists. One example is Laura U. Marks. In her book, *Enfoldment and Infinity: An Islamic Genealogy of New Media* (2014). She sought to establish parallels and relations between Islamic art and computer-generated systems-based art and observed, "The universe is not dualistic, but folded" (2010:271). In contrast, but also through the lens of Bohm's theories, the current research examines a range of questions that arise from an art practice investigating light, matter and the immaterial. Although the outcomes are very different, there is an alignment of viewpoints, each exploring the key textile metaphor of folding from

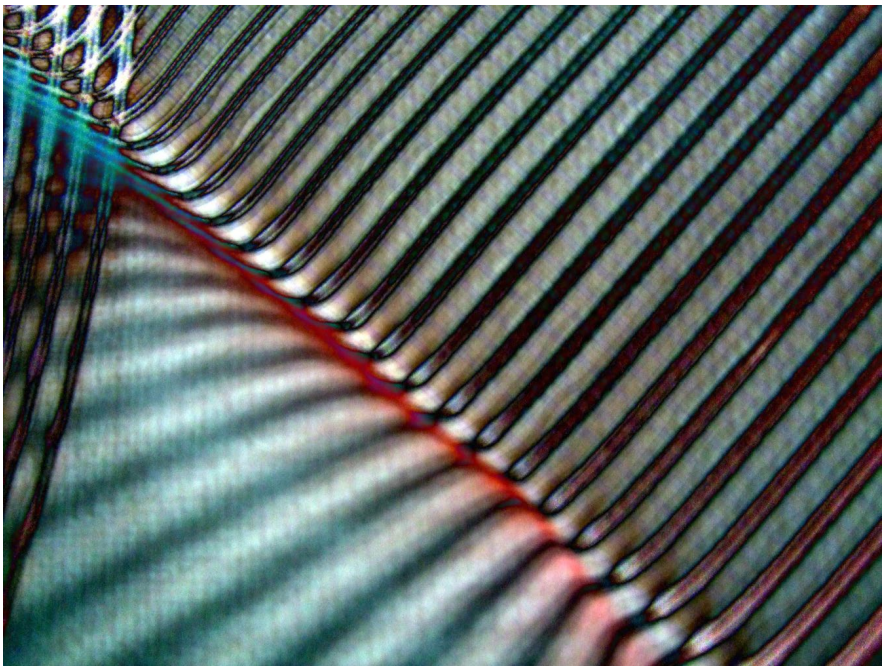

Image 63: Photograph of striped translucent fabric, solarisation process. 2021.

across a variety of disciplines (science, philosophy and art). Using a comparative approach, Marks looks at the historical, social, theoretical, philosophical and spiritual connections and identifies intersecting and corresponding philosophical concepts drawing on the work of Charles Sanders Pierce, Michel Foucault, Walter Benjamin and Ilya Prigogine. She defines her central device of using a folding/unfolding as the relationship between the hidden order (infinity) and the manifest (this is identified as the 'edge of becoming' in the current research, see Chapter 1).

Drawing on an Islamic worldview, Marks finds correspondence with the Arabic terms: *zâhir* and *bâtin. Zâhir* describes the unfolded explicate order—the surface, the outer manifest forms that conceal *bâtin*, the hidden inner truth—the enfolded implicate order. Marks also proposes an unfolding/enfolding aesthetic through which to read both Islamic and contemporary abstract art. It is primarily drawn from Bohm's enfolding/unfolding model of the universe but also includes ideas from Deleuze and Guattari.

While Deleuze describes two planes—the image and the infinite—that constantly unfold and enfold and form the margin between the virtual and the actual, Marks poses three levels to her aesthetics of enfolding/unfolding (2010:6). By employing the triadic relation of signs of Charles Sanders Pierce, she inserts a third level to the image and the infinite—information which is an intermediate level that serves as a bridge between the boundaries of the image and the immaterial world of the infinite. She sees it as the interface through which the semiotic passes before images can arise, suggesting a computer programme code as such an interface. Therefore, the image is, in turn, an interface to information which is, in turn, an interface to the infinite—they enfold each other and unfold from each other. Bohm's later writings include theories of 'active information' as a third component to the implicate/explicate, mind/matter dualities to form a triad of aspects to reality; however, Marks does not acknowledge any influence from this development in Bohm's work.

She uses the unfolding/enfolding aesthetic as an analytic tool and proposes that the three levels of her image, information and infinity provide a new way of thinking about both Islamic and contemporary art, enabling one to distinguish artworks as being either performative (with the movements of enfolding and unfolding between levels) or being representational (simply an image). Under these criteria the artworks created for this research would be determined as performative. The art practice in this research is not merely representational as it is also performative (Bolt 2004:11-52).

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This chapter has seen examples of correspondences across wide-ranging fields that support textile thinking as a flexible methodology that can be used in many different ways. As cloth is something we all understand, it is common to use textile metaphors to

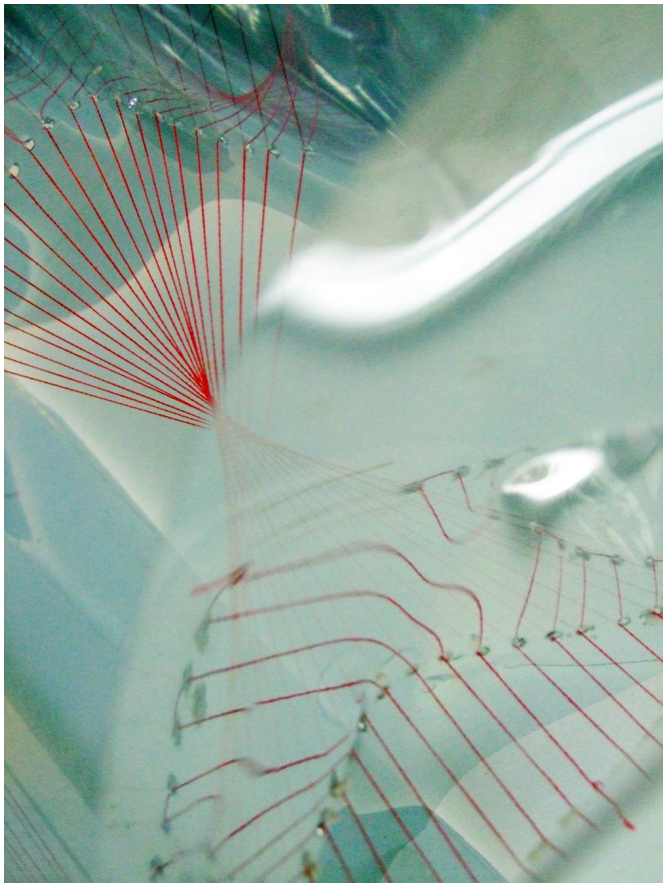


Image 64: Two-way mirror drilled with holes, mirror film, red thread. 2015.

concretise challenging ideas. Examples of this are represented in a variety of fields; however, by its very nature, it is difficult to quantify the role played by the applied textile thinking in this enquiry. The benefits are evident in many ways; most importantly, textile thinking braids together the multiple strands and helps materialise the ephemeral themes within the artworks and installations

Textile thinking facilitates managing the complexity of interweaving the many strands of scientific and philosophical thought through the multiple processes of mixed-media artmaking and allows for an integrated but structured whole. Methodologies of art practice-based research and textile thinking are spun together to permit non-linear interconnectedness and characterise the light-inspired themes. The resulting artwork outcomes incorporate and synthesise these factors more successfully than the linear text of this thesis.

The following three chapters examine three scientific perspectives that are foundational to this thesis; each centres on a textile metaphor that serves to clarify aspects of the science which has its roots in the study of light. Interference *fringes* in Chapter 5 demonstrate the wave nature of light; quantum *entanglement* is one of the bizarre characteristics of light discussed in Chapter 6 and, lastly, there is a more in-depth examination of *folding* with the enfolding/unfolding of David Bohm's implicate/explicate orders and the holomovement in Chapter 7.

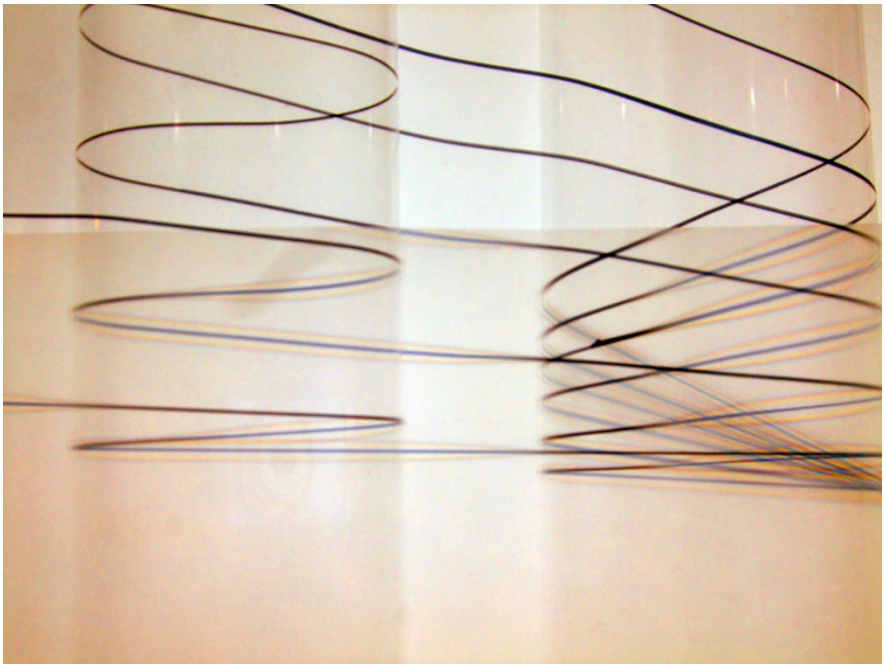


Image 65: Black ink drawings on diffraction grating, LED light. 2017.

Part III—The Science of Light: Unravelling Threads of Influence

Chapter 5
Beyond the Fringes—Quantum Light

Textile Notion #6—Fringes

Fringes were originally formed from the warp threads of a woven cloth which were twisted or braided to prevent the cloth from unravelling. The word fringe originates from the Old French 'frenge' which evolved from the Latin 'frimbia' meaning fibres, threads, fringe. However, sculptures and written accounts give evidence of fringes on clothing as early as 3,000 BC in Mesopotamia. Other meanings include margins, edges and non-mainstream.

In physics, fringes are the light or dark bands produced by interference or diffraction of light and are known as interference fringes and diffraction fringes respectively.

Introduction

Investigations into the nature of light in this enquiry first led to looking at its scientific principles which led deeper into quantum physics' strange and paradoxical world. Quantum physics reveals a confounding array of non-intuitive properties of light and phenomena at the edges of known reality—at the edges of becoming. These paradoxical behaviours are puzzling and it became clear that it would be easy to get lost in a myriad of quantum questions and themes. Fortunately, the study to gain a layman's understanding of this baffling world uncovered that many of these strange phenomena are linked to a single series of experiments, the famous double-slit experiments. They serve as a point of convergence for many of the issues in quantum physics. As Anil Ananthaswamy observes in *Through Two Doors at Once: The Elegant Experiment That Captures the Enigma of Our Quantum Reality*,

> Decade after decade, hypothesis after hypothesis, scientists have returned to this ingenious experiment to help them answer deeper and deeper questions about the fabric of the universe (2018).

Richard Feynman stated in his Cornell lecture (1963a) that any situation in quantum mechanics can be explained afterwards by remembering the two-slit experiment. He remarked that the double-slit experiment is "impossible, *absolutely* impossible to explain in

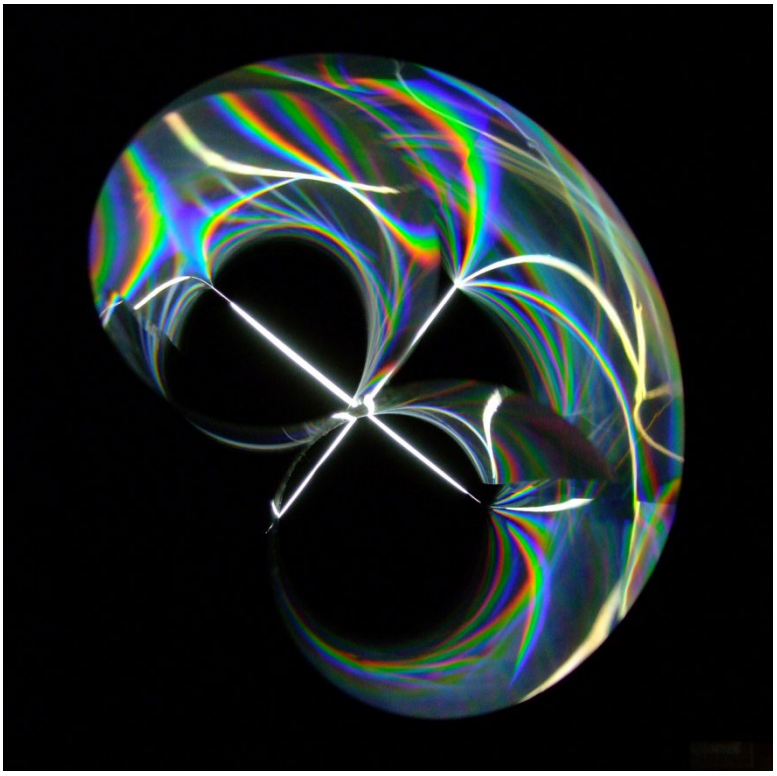


Image 66: Black paper cut with two-slits, diffraction grating, LED light. 2019.

any classical way and has in it the heart of quantum mechanics," adding, "In reality, it contains the only mystery" (cited in Ananthaswamy 2018:266).

Focusing on the double-slit experiments anchored and limited the scope of this enquiry. Investigating the themes and tropes arising from these experiments oscillated between reading, writing and making. These very different ways of thinking supported and extended each other. The knowledge gained included wave/particle duality which became a central recurring motif in the art for this research. Apparatus used in the double-slit experiments (primarily as 'beam-splitters'—half-silvered mirrors, prisms and dichroic materials) were appropriated and used as art materials producing wave effects that represent, for example, quantum entanglement (a non-local effect) and the 'observer effect' where every act of observing simultaneously causes a transformation of what is being observed. In this project, the viewer activates many of the artworks, seeing different views depending on viewpoint; nevertheless, all possible views exist in the work at all times (see Part IV). Understanding the physics has been important in presenting these ideas and their implications through the artworks and a brief review of the science, starting with the earliest double-slit experiment is included below for the reader's benefit.

Young's Experiment—Interference Fringes

The double-slit experiment was first performed in 1801 by English polymath Thomas Young and is often referred to as Young's experiment. There had been much debate on the nature of light in the preceding centuries, one view being that light is made of a stream of particles (what Isaac Newton called "corpuscles" in his treatise of 1704, *Opticks: or, A Treatise of the Reflexions, Refractions, Inflexions and Colours of Light*). A second position was argued in the 1600s by both Descartes in *The World or Treatise on the Light* (1629-33) and Dutch scientist Christiaan Huygens (1629-1695) who both proposed that light has a wave-like nature. This would explain why, for example, light changes direction when it travels through different materials. In 1905, Einstein theorised that light is emitted as light energy but with definite particulate qualities. He called them *photons* and realised that these "light-quanta" were the same quanta Max Planck had discovered. Einstein was baffled by the quantum nature of light, saying in 1951,

> All the years of conscious brooding have brought me no closer to the answer to the question, "What are light quanta?" Of course today every rascal thinks he knows the answer, but he is deluding himself (cited in Zajonc 1995:ix).

Experimentally, light can be seen as either particles or waves; these have very different, contradictory and mutually exclusive properties. Particles are described as behaving more like billiard balls following a trajectory and bouncing off surfaces, whereas, light waves are

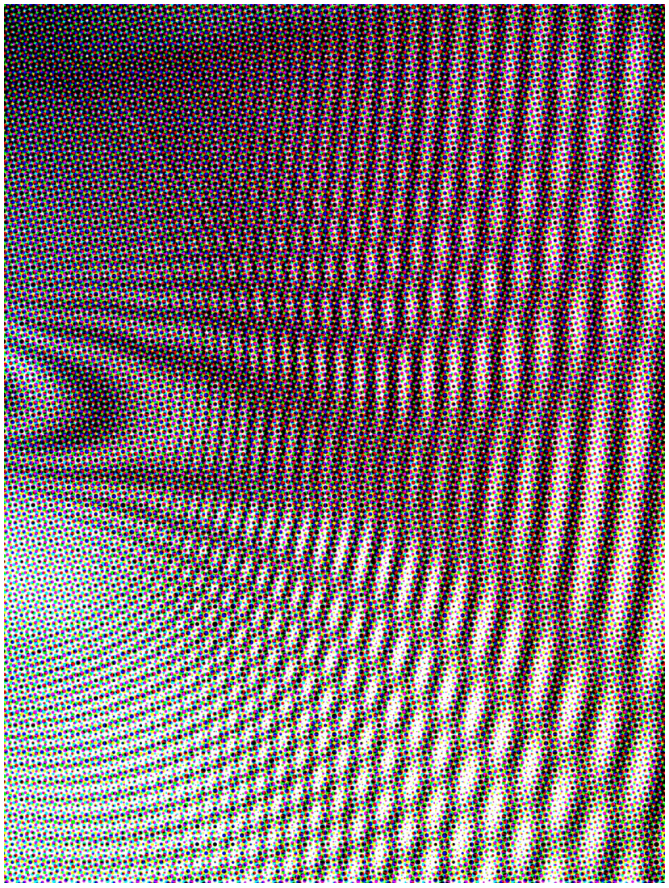


Image 67: Striped translucent fabric, halftone process. 2019.

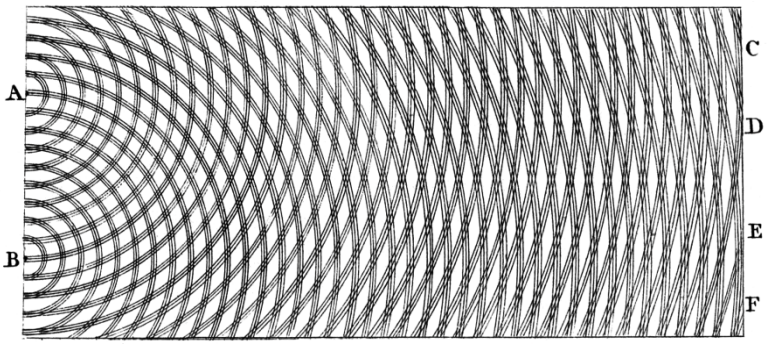
disturbances in a field, more like water or sound waves spreading over an area. Neither view fully explains the phenomenon of light. Both are necessary.

The conceptual simplicity of the experiments has not changed since Young did his experiment; however, they have become technically more and more sophisticated in the search for answers to the questions they asks (Ananthaswamy 2018:22). Although Young's experimental apparatus was very basic, the results of this (and subsequent) experiments belie this simplicity, raising many of the complex central, 'hard' quantum questions in physics, including quantum entanglement, the 'observer effect', non-locality and questions of wave/particle duality. Young presented his experiment to the Royal Society of London in 1803 where his simple apparatus included a sunbeam shining through a hole in a window shutter and then through holes in cardboard (pierced by a fine needle). The original experiment was recreated and demonstrated by *Veritasium* in 2013 and can be viewed in a YouTube video at https://www.youtube.com/watch?v=Iuv6hY6zsd0.

Particles and Waves

Young demonstrated that the light shining through the holes resulted in a series of coloured bands with dark spaces between them, a series of alternating lighter and darker areas in a row, with the brightest being in the middle behind the holes (See Fig. 8). This pattern is characteristic of wave interference and is caused by fringes created through the constructive and destructive interference of the light waves passing through each of the two slits. It was not the expected particle pattern of two bright bands—if light were made of a stream of particles, one would see two bright bands of light hitting the surface behind each of the slits. Young used sunlight as his light source, and, because the spectrum makes up sunlight, he saw spectrum colours unfold around the edges of the brighter fringes. As each of the colours within sunlight has a different wavelength, they each refract differently. Nowadays, double-slit experiments are usually done with a single wavelength of light, usually lasers.

Figure 8.
Thomas Young's sketch of two-slit diffraction of light. Narrow slits at A and B act as light sources and waves interfering in various phases are shown at C, D, E and F.



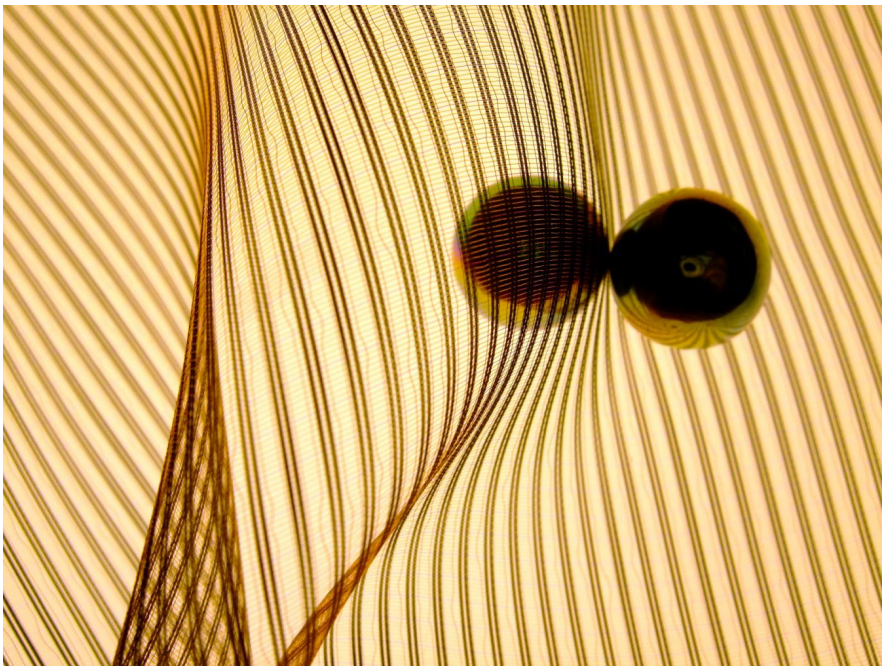
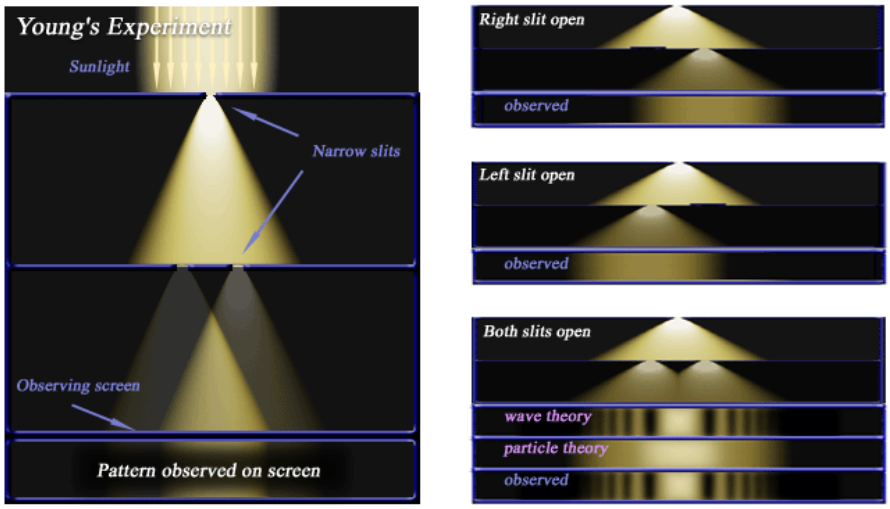


Image 68: Striped translucent cloth, two black marbles. 2016.

Figure 9. Diagram to show light patterns in Thomas Young's two-slit experiment.



By having the two slits open, the final 'observed' image in this diagram (See Fig. 9) of light patterns created by a double-slit experiment depicts the intermittent banding of the interference fringes, illustrating that light has a wave-like nature.

Further Developments of the Two-Slit Experiment

In 1924, Louis de Broglie (1892-1987) postulated that both photons and electrons (i.e. both light and matter) behave similarly to each other (Ananthaswamy 2018:66). George Paget Thompson and Clinton Davis verified this experimentally three years later. Theoretical physicist, Richard Feynman, remarked that both photons and electrons, though different phenomena, behave in exactly the same way, "That is they're both screwy" (cited in Ananthaswamy 2018:7). In 1965 Feynman developed thought experiments (Gedanken) that posed that firing single quantum particles through the apparatus (with a time delay between each firing) would still produce an interference pattern. This was counter-intuitive as, in classical physics, interference requires a second wave from a second concurrent electron to create the bands of constructive and destructive interference so there should be no possibility of any wave interference from a single particle. Testing this hypothesis was not technically possible until twenty years later when Alain Aspect verified the experiment in the laboratory with photons in 1985. Later, in 1989, Akira Tonomura also succeeded, but this time with electrons. Tonomura, a Japanese physicist, is best known for his development of electron holography and his experimental verification of the Aharonov–Bohm effect (see https://www.youtube.com/watch?v=lf24ncsc3LQ).

Astonishingly, just as Feynman predicted, when Tonomura's experiment is run over a period of time and the (apparently random) landing locations of successive particles are sequentially recorded on a sensitive plate, the pattern of alternating bright and dark

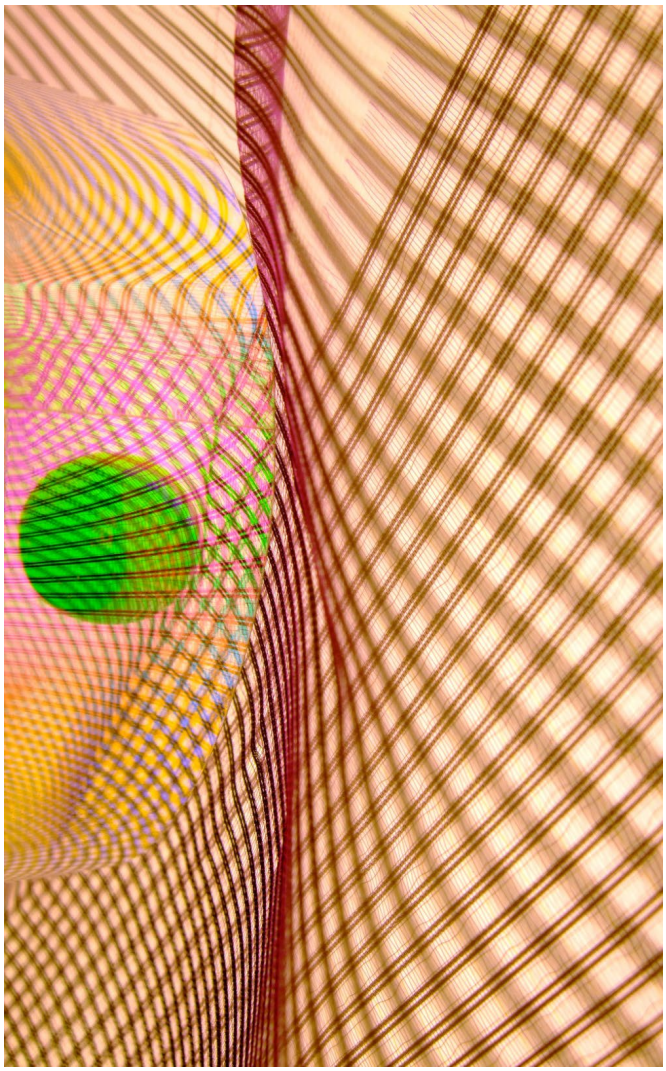


Image 69: Striped translucent fabric, dichroic film, black marble, LED light. 2016.

fringes appear—indicating the wave property of interference. The fact that the electrons register as a single spot on the landing plate suggests that they have particle-like properties; however, collectively, they produce an interference pattern so that a wave property can be attributed to each single electron as well; therefore, both particle and wave properties are registered. The question as to what is going on arises; seemingly, the electron takes one path through one slit *and* the other slit at the same time and appears to be in two places at once (this phenomenon is called quantum superposition). To paraphrase Paul Dirac, it appears that each electron is a wave interfering with itself (cited in Ananthaswamy 2018:84).

During the material investigations for this enquiry, using a striped transparent fabric enabled explorations which created visual examples of interference patterns. In an attempt to create a practical expression of the idea of a wave from a single electron interfering with itself, a single piece of this cloth was folded over itself so that the patterns of the stripes were visually combined. The striped pattern interfered with itself to produce dynamic moiré patterns (see next chapter for more on the significance of moiré).

The Observer Effect

One of the many strange examples of quantum weirdness revealed by the double-slit experiments is the observer's effect on the outcome. When the experimenters attempt to observe which path an electron or photon takes through the apparatus with which-slit detectors, the interference fringe (wave) pattern disappears and reverts to the particle pattern of two bands directly behind the slits captured on the plate. If the detector remains in place but is switched off (and is therefore not detecting), it reverts to a wave pattern again. It is as if the particles in the experiment 'know' whether or not they are being watched and they behave accordingly—as a particle if they are being detected or as a wave if their route through the slits is not observed.

The role of the observer/viewer is key to the art—the viewer activates it by seeing different views depending on viewpoint. They see one thing from one position and something different from another place and this challenges the belief that we are separate, however, everything is interconnected—we are not isolated individuals and cannot step outside the whole. As previously mentioned, the work exists in all states at once—how you see it depends on where you see it from. The other states still exist even if you don’t see them at a particular moment from your specific vantage point and the works question viewers' fixed viewpoints, positions and perspectives, and through the novelty of the visual experience, they can expand their perception via the RAS.

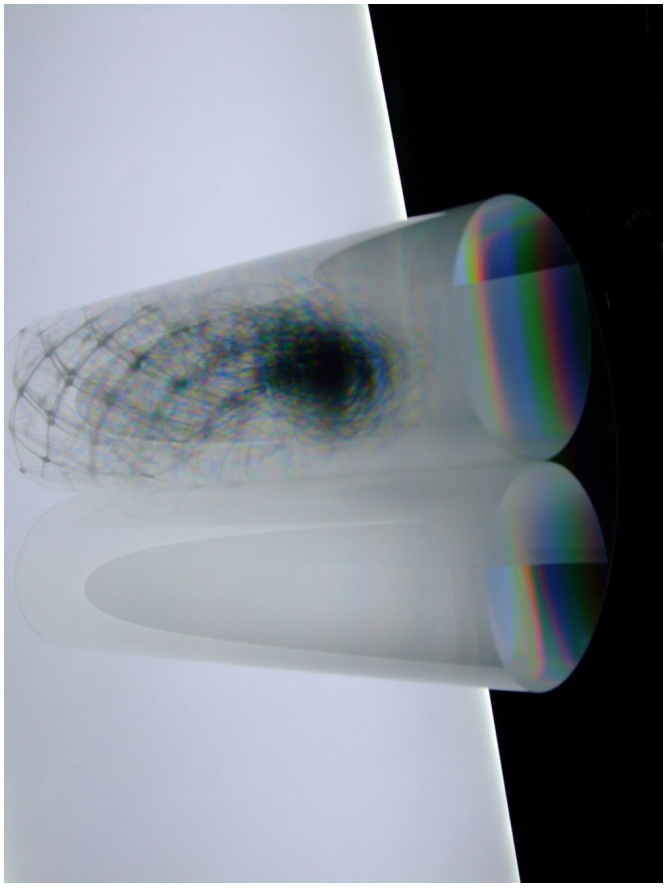


Image 70: Diffraction grating, birdcage netting, black card, LED light. 2016.

Appropriating Apparatuses

The two-slit experiment expands the understanding of the nature of light beyond its classically understood properties, revealing bizarre quantum properties which include non-locality, entanglement, the complementarity of subject and object, the observer effect (where photons appear to 'know' if an observer is observing) and wholeness. The experiment is significant to this project because it offers a single gateway into the quantum world by revealing many of the non-intuitive quantum questions and themes that arise from its results. Apparatuses used in the experiments become materials for making the material investigations and creating the artworks. With this reconfiguring of the apparatus, the artworks themselves become an 'apparatus' for presenting a new way of seeing. Karen Barad (see next chapter) argues that apparatuses are not merely neutral devices, laboratory instruments for probing the natural world, but that,

> Apparatuses are specific material reconfigurings of the world that do not merely emerge in time but iteratively reconfigure spacetimematter as part of the ongoing dynamism of becoming (2007:142).

The final exhibition for this enquiry, *Quantum Light—Beyond a Crisis of Perception,* included a human scale half-silvered mirrored vitrine, *Beyond Dualities Pavilion*. Viewers entered the mirrored space, experiencing the expanded virtual space of the multiple reflections, becoming part of an origami world. With this reconfiguring of space and perspective, it became an 'apparatus' presenting a fresh way of seeing and perceiving. This challenges a historically experienced fixed perspective and loosens the tendency to view the world from a fixed viewpoint, potentially enabling a shift in perception in the RAS.

In addition to ordinary mirrors and prisms, three apparatuses that are usually used as beam-splitters in the experiments (diffraction grating, half-silvered mirror and dichroic materials) are appropriated and incorporated into mixed-media artworks for this research. In addition to being used for their aesthetic value, they serve to express paradox, wholeness, non-locality and question duality. Using such materials in this way goes beyond using them as mere metaphors and activates their unique physical effects to become a visual/aesthetic enacting of the phenomena in question. From this, the viewer can experience a sense of bizarre quantum behaviours through the artworks (see Part IV). The most successful materials in achieving this are the ones that are used as beam-splitters in the experiment such as diffraction grating.

Diffraction Grating

The two slits in the experiment serve as a simple grating composed of only two bands, whereas diffraction grating is formed of many, many bands per inch which are, in effect, a

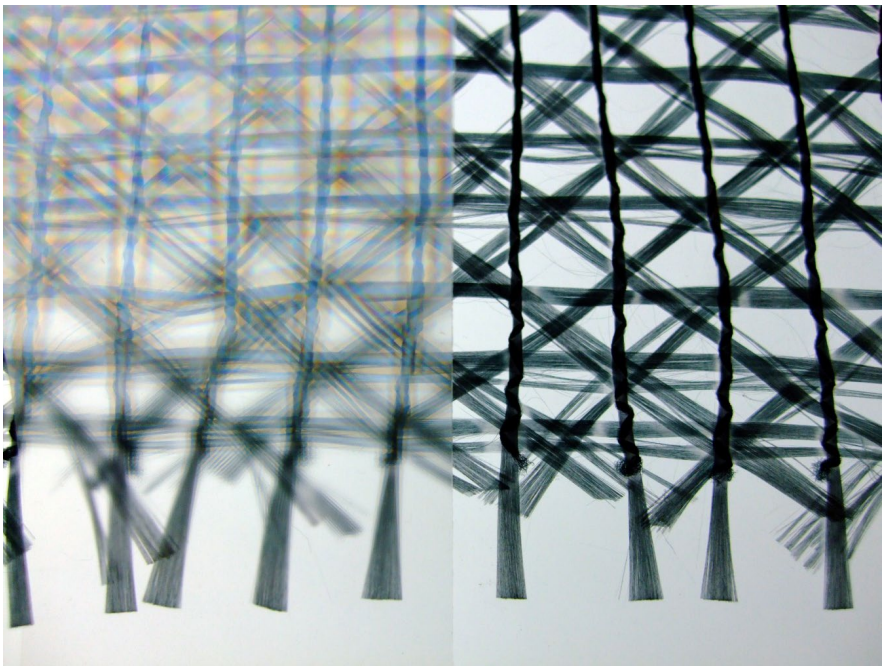
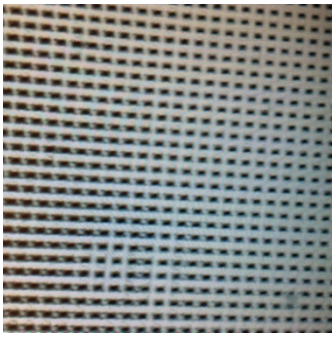


Image 71: Tri-axial cloth, diffraction grating, LED light. 2015.

multitude of microscopic slits. During the material investigations into diffraction grating, it was photographed through a microscope at 40x magnification (See Fig. 10). The lines are spaced at 13,500 lines per inch on a double axis. The grid formed by the horizontal and vertical axes is reminiscent of the warp and weft threads that make up woven cloth. Although both single and double axis diffraction grating was tested, the latter was chosen as an art material because of its correspondence with the grid, also the optical effects are more dramatic. See Part IV for a description of the use of diffraction grating and its effects and implications in the current research.

Figure 10.
Photograph: of diffraction grating through a microscope at 40x magnification.



Diffraction grating is an ideal and appropriate material for exploring this research's ideas; it has fascinating properties of splitting light into the spectrum, with either aesthetically pleasing softness or intense, saturated colours depending on the ambient light conditions (see Chapter 8). It is worth examining more closely here.

Scottish mathematician and astronomer James Gregory first discovered diffraction grating in the mid-1600s by passing sunlight through a bird feather. He observed that white light shining through the fronds of the feather separated into a pattern of spectrum-coloured interference fringes with a bright spot in the centre (cited in Rigaud 2013). This parallels Young's experiment which was performed two hundred years later in 1801. The first man-made diffraction grating was created in 1785 by an American astronomer and inventor, David Rittenhouse, who strung fifty hairs between two finely threaded screws with an approximate spacing of about 100 lines per inch. Later, in 1821, Bavarian physicist and founder of stellar spectroscopy, Joseph von Fraunhofer, developed a similar diffraction device from wire. Nowadays, diffraction grating is printed, embossed or ruled with a diamond cutter, creating gratings of up to tens of thousands of lines per inch.

Image 65 opposite is from a series of material investigations probing the effects of interference fringes. It demonstrates how diffraction grating separates the wavelengths of light into the spectrum colours—in effect disentangling all the wavelengths in white light to reveal the visible spectrum. Diffraction grating sits across half of the tri-axial cloth which has an open weave structure. Its placement allows a comparison between the effect of the

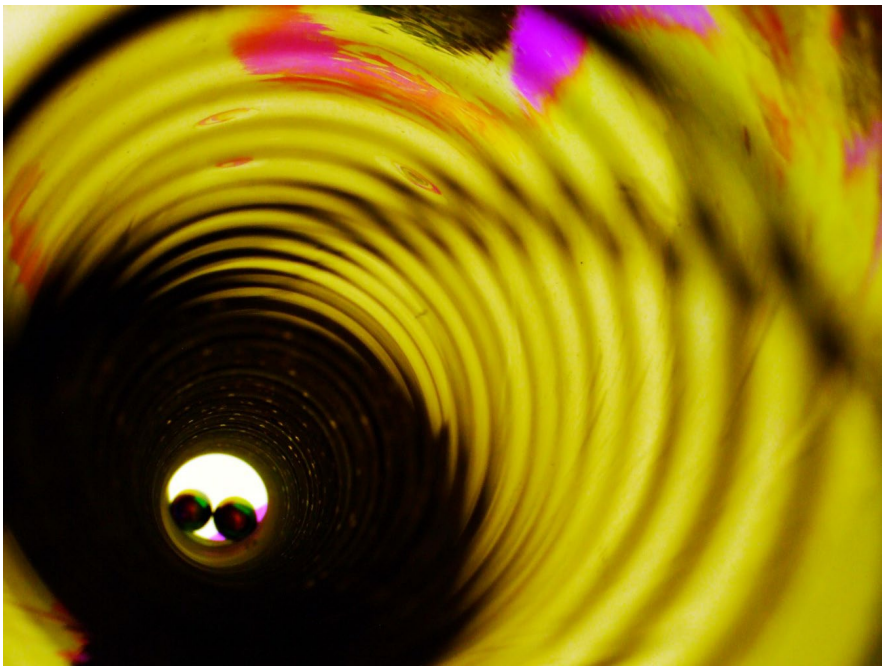


Image 72: Dichroic film, coiled spring, two tempered metal marbles. 2016.

diffraction on the fibres of the cloth and the 'naked' cloth which has been cut to reveal the fringes formed by its warp threads. The light diffracts around the edges of the fibres in the cloth disrupting the borders and complicating the form.

Interpretations of the Two-Slit Experiment in Quantum Physics

Even though physicists cannot predict events and outcomes of quantum phenomena, they do find coherent patterns of behaviour—it is a matter of probability and, as they don't yet understand the reasons, there are many interpretations of what is happening. This is subject to much debate in physics and interpretations include the orthodox Copenhagen interpretation, many-worlds interpretation, relational quantum mechanics and the de Broglie-Bohm theory.

In the standard interpretation, the founder members of quantum mechanics proposed in the 1920s that there is a 'collapse of the wave function' into the particle state when the path through the slits is observed. The wave-function (represented by the Greek letter ψ - psi) is a mathematical description; it is not a real wave but is a probability wave, which is said to spread out *until* a measurement is taken, which causes the wave-function to 'collapse' into a definite value, i.e. a particle. Before the collapse, the electron is said to be in a state of super-position—i.e. being in two states (wave and particle) at once. Not all physicists agree with this interpretation and Schrödinger devised his famous thought experiment to illustrate what he saw as the problem with it if applied to everyday objects. In his thought experiment, a cat is sealed inside a steel box with a flask of poison and a radioactive source. The cat is described as existing in super-position—of being in a cat-dead *and* a cat-alive state until the box is opened when the cat is observed to be in one state or the other.

This in-between state, before the collapse of the wave function into the particle could be thought of as a transition from the 'possible' to the 'actual' and was explained by Werner Heisenberg in the following way,

> [The probability wave] meant a tendency for something. It was a quantitative version of the old concept of "potentia" in Aristotelian philosophy. It introduced something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality (cited in Aerts 2015:138).

Uncertainty and Complementarity

Heisenberg's uncertainty principle or indeterminacy principle proposes that there is a limit to what we can simultaneously know about specific pairs of physical quantities; for

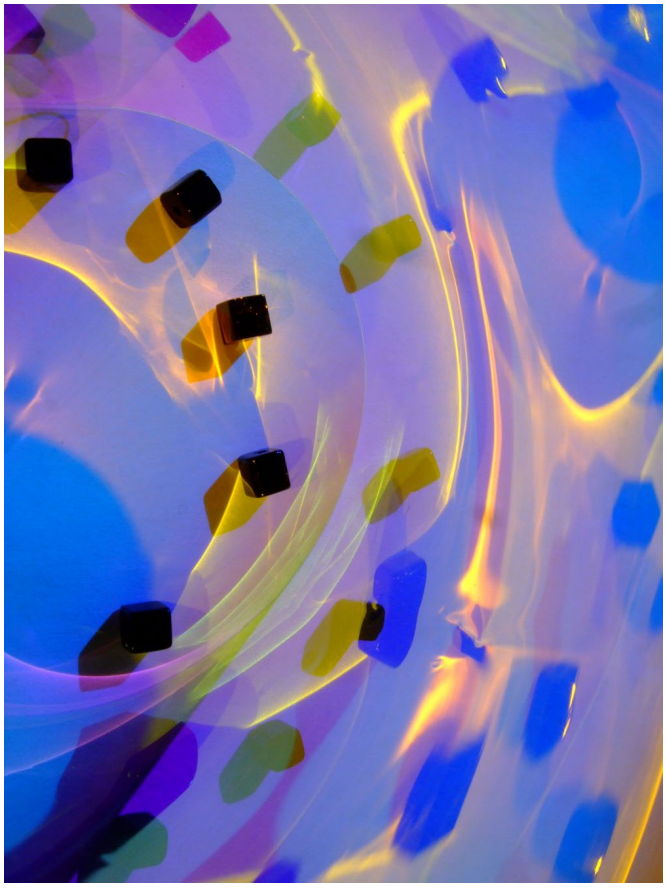


Image 73: Dichroic film, black beads, sunlight. 2021.

example, the more we know about a particle's position, the less we know about its momentum, and vice versa. Heisenberg theorised that the not knowing is not because the apparatus, technique, or the observer are inadequate, but rather, that it arises out of the relationship between quantum particles, waves and the apparatus.

On the other hand, Bohr's complementarity framework offers an alternative view. It says that it is not what we *know* about the position and momentum of a particle simultaneously (as in Heisenberg's view) but that particles do not *have* determinate values of position and momentum simultaneously. In Bohr's complementarity, either particle or wave becomes the determinate property depending on the apparatus used while the other 'complementary' property remains indeterminate. Therefore, Bohr theorised that it is not what we *know* about the nature of reality, however, but is *about the nature of reality itself* which calls into question Western metaphysics' historical belief that the world is made of individual things with their own independent sets of determinate properties—everything is interconnected (Wilkins 1987:338-360).

Supported by this scientific viewpoint, creating art incorporating a position of interconnected unity is a central aim of this project. Interconnected wholeness is one of the central tenets of Bohm's theories and although Chapter 7 is devoted to Bohm's theories, in the light of the viewpoints of the other physicists, it is worth considering his position on the two-slit experiment here.

David Bohm and the Double-Slit Experiment

In 1951, Bohm published one of the most lucid textbooks on quantum mechanics, *Quantum Theory* (Ananthaswamy 2018:172), which he wrote to gain a deeper understanding of the subject. However, he was unsettled by the prevailing theories which proposed that the act of observation creates reality. Einstein felt the same way, his theories contradicted Bohr's uncertainty principles, leading him famously to ask fellow physicist Abraham Pais one moonlit evening, "Do you really believe the moon is not there when you are not looking at it?"

Bohm pondered deeply on the implications of the two-slit experiments. He felt that particles and their trajectories must exist independently of observation while still maintaining the uncertainty principle which he considered to be "one of the most fundamental deductions of the quantum theory" (cited in Ananthaswamy 2018:150). He developed theories that supported the uncertainty principle (which permitted quantum properties, such as non-locality) but nonetheless included a deterministic formulation of quantum phenomena. In 1952, following discussions with Einstein, Bohm presented a

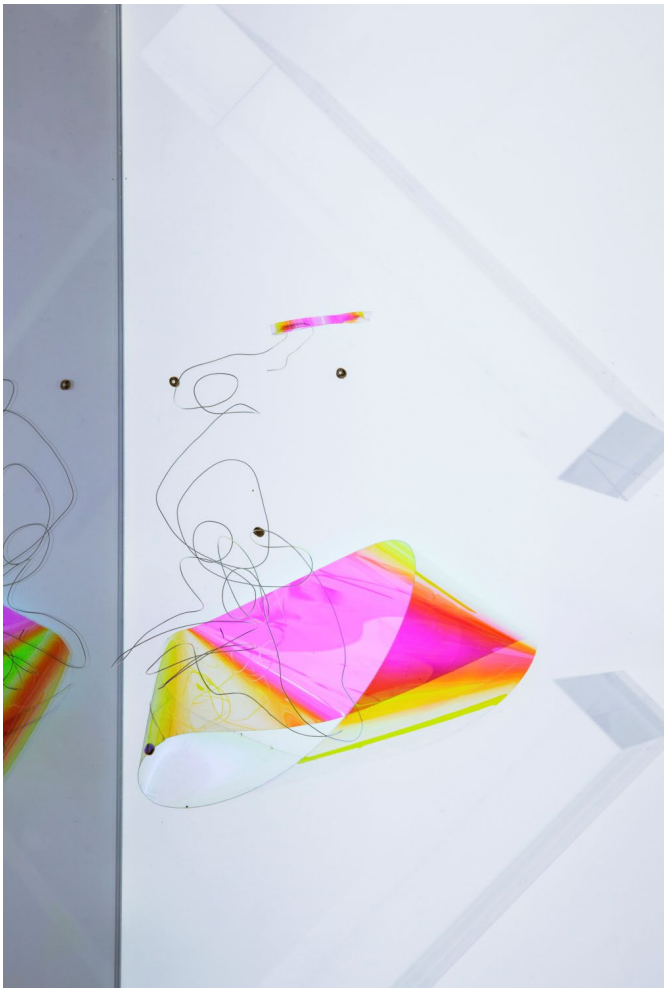


Image 74: *Unfolding Light and Space #1.* Detail view. Prisms, two-way mirror, wire, gold beads, dichroic film. LED panel. Photograph Ibolya Ferher. 2015.

paper, *A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden Variables',* where he proposed a "pilot wave" theory that could explain the contradictory experimental observations of the two-slit experiment. Bohm assumed that an electron had both wave and particle properties simultaneously (rather than the either/or scenario favoured by Bohr). He proposed that a particle had a trajectory and was accompanied by a type of quantum field. This quantum wave precedes the particle and goes through both open slits in the experiment, producing an interference pattern. Bohm likened it to a ship on automatic pilot being guided by radar (1989).

After publishing his paper, Bohm became aware of the earlier theories of the French prince Louis de Broglie and discovered that his own theories were not novel. In 1924 de Broglie had also theorised that, like photons, electrons had wavelike properties, proposing in 1927 that reality is formed of particles that are guided by a "pilot wave", which behaves like a wave function and evolves according to a form of the Schrödinger equation. He argued that reality was not a wave *or* a particle; rather, it was a wave *and* a particle. However, de Broglie could not explain aspects of the experiment when challenged by Wolfgang Pauli and he abandoned his pilot-wave theories. On the other hand, Bohm pursued his ideas to their logical conclusion and the pilot-wave theory is still referred to as the de Broglie-Bohm Theory today. Bohm assumed that an electron is always accompanied by a field. In the experiments, a quantum wave goes through both open slits even though the particle goes through only one.

Bohm had introduced a new element into his mathematical equations, an information field he called the quantum potential 'Q', which he derived from the Schrödinger equations (Pylkkänen 2010:165-170). The quantum potential provides information to the electron, linking it to the rest of the universe and the wave function still evolves according to the Schrödinger wave equation; however, it never collapses (as in orthodox quantum mechanics), opening up new possibilities for causal interpretations such as the Broglie-Bohm theories. Recent state-of-the-art double-slit experiments with single electrons and single photons and using slits of different widths, conducted by Vietnamese physicists, Vo Van Thuan and Vinh Vu Duc (2021, 2022), have shown that it is possible to simultaneously observe both wave and particle features.

A helpful understanding of the double-slit experiment is provided by fluid mechanics researchers Yves Couder and Emmanuel Fort (2006), who created models that offer a classical analogue version of the experiment that demonstrate the simultaneous coexistence of both particles and waves. A droplet of silicone oil, called a 'walker', bounces over a vibrating surface of the oil and is guided by the wave it creates; as it bounces, the wave creates and sustains each bounce. When the droplet and its

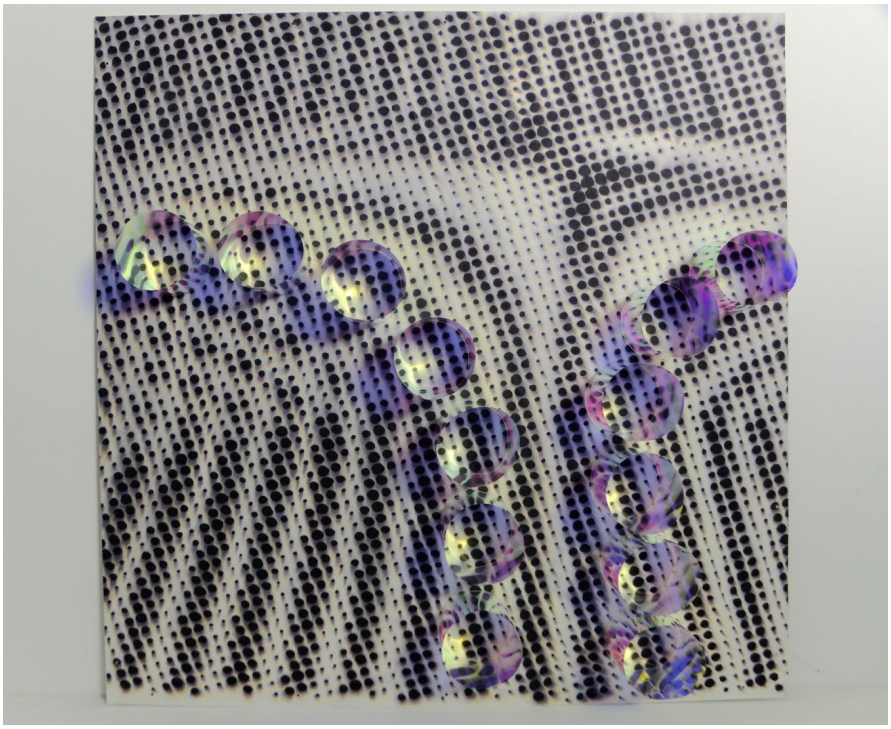


Image 75: ***Particles on the Edge of Becoming #1*****. Shoji paper, dichroic film, black ink, mirror, wooden frame. 595mm x 595mm x 80mm. 2017.**

accompanying wave encounter a barrier with two slits, despite there being only one droplet that goes through one slit, the wave goes through both slits at once and a wave interference pattern is created (see https://www.youtube.com/watch?v=W9yWv5dqSKk).

An important understanding drawn from the de Broglie-Bohm view is the inextricable coupling of the wave and the particle (a wave/particle duality) and the wider implications of unifying dualities, in particular, the importance of eschewing an *either/or* position for one of *and/both*. We live in divisive times, and one of the key threads and a persistent aim of artistic research is expressing the possibility for unifying dualities without pitting one against the other or sacrificing one over its opposite. The works offer an experience where something is more than the sum of itself and its polar opposite. Embracing congruency and wholeness in this way rather than coming from a position of division, allow the potential for unexpected and more open and inclusive outcomes.

Particles on the Edge of Becoming #1 (see Image 75 opposite) is an example of how the themes that emerge from the double-slit experiment inhabit the work. After its creation, reflection on this piece revealed that it closely resembled the accumulation of particles forming interference fringes in the Tonomura experiment (See Fig. 11 below).

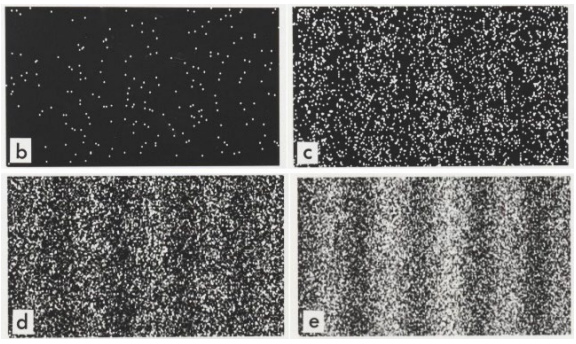


Figure 11.
Results of a double-slit-experiment performed by Dr. Tonomura showing the build-up of an interference pattern of single electrons. Numbers of electrons: (b) 200, (c) 6000, (d) 40000, (e) 140000.

The background image comprises a series of hand-drawn dots (particles) of various sizes; their size and density create alternating darker and lighter lines. The lines diverge into a hyperbolic shape in the centre of the image and two rows of dichroic tubes follow this curve; the shape of the curve represents the wave which is composed of rows of dots. The reflections of the dots in the curved surface of the dichroic tubes stretch and morph, further representing waves. In this way, "a point turns into movement and line" (Klee 1961:77). Both the colour and form of these reflections alter as the viewer moves—the observer and the observed are in a dynamic relationship.

*

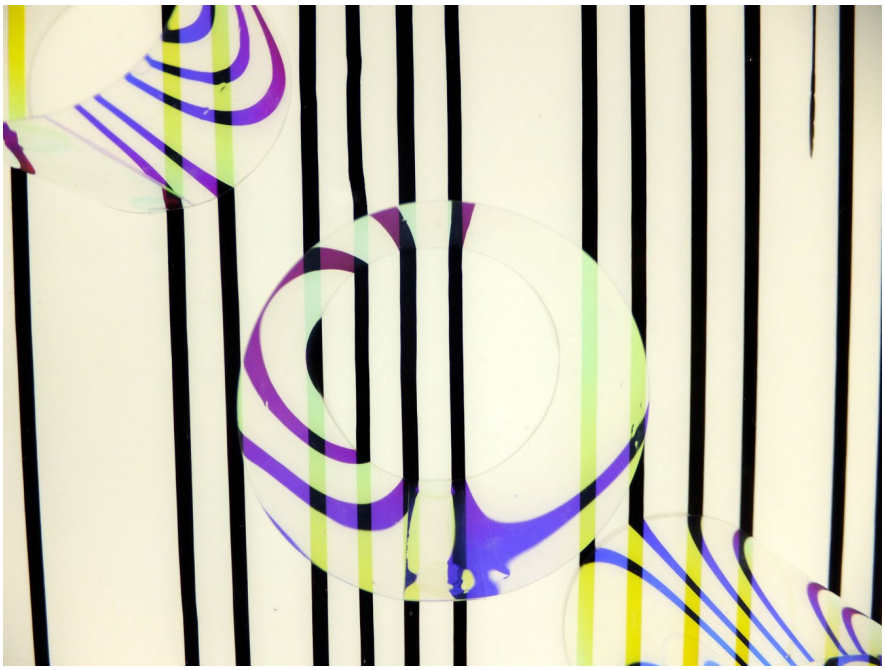


Image 76: *Quantum Questions—Line Interrupted #1.* LED light panel, dichroic film, calligraphy ink, Japanese Shoji paper, mirror, frame.
595mm x 595mm x 80mm. 2017.

In this enquiry, the breadth of quantum physics is viewed from the vantage point of a single set of experiments—the double-slit experiments—and are a means to approaching the complexities of quantum physics. The artworks and material investigations created using the apparatus of the experiments are central to this research and they illustrate, represent and enact the themes that arise.

The first thing the double-slit experiments revealed was that light directed through two very narrow slits resulted in interference fringes of the wave nature of light. In later experiments, counter-intuitively, when one photon (or electron) is sent through the slits one photon at a time, the accumulated results show that, over time, interference fringes still occur, suggesting self-interference—that a single photon acts like a wave that can interfere with itself (May 2014:32). However, if a detector is set to monitor which slit the particle passes through, the photon behaves as a particle; it is as if it knows when it is being watched. These experiments demonstrated the fundamentally dual nature of light, that it is *both* a particle *and* a wave, leading particle/wave duality to become a recurring motif. This unified quantum duality is examined through the materials from the experimental apparatus, such as dichroic and diffraction grating films and the findings from the material investigations of these materials are fed through into the artworks.

The many implications of this experiment are profound and bewildering (Ananthaswamy 2018:3). For example, the inseparability of the observer and the observed led some physicists to conclude that the act of observation creates reality. In response to this, the artworks invite the viewer to engage with them, demanding their bodily movement in the action of looking. They reward this activity with playful views of changing shapes, colours and experiences of superpositions of dual opposites. As the artworks present unfixed, shifting experiences, they interrogate fixed perspectives from positions of and/both rather than either/or; they serve to open up the perceptual limits of the RAS towards possibilities for new thinking.

A large-scale installations in the final exhibition, *Quantum Light—Beyond a Crisis of Perception,* reference the two-slit experiment and particles and waves. The space beyond the huge *Double Aperture Moiré Wall* can be entered through one of two slits, the viewers can choose which slit they enter. As they approach and move through the gallery, the viewers experience the moiréd dance of the layered fabric that lines the wall. A multitude of large mirrored discs line the walls and images selected from the material investigations dataset are projected onto a circular screen with a wavy surface. The projections zoom in and out in a breath-like pulsed rhythm.

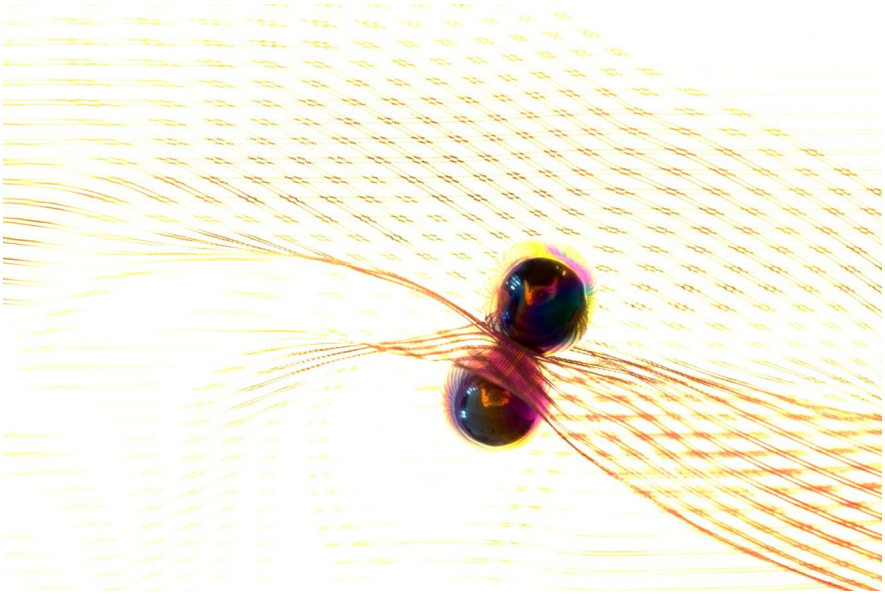


Image 77: Striped translucent cloth, two marbles, Photoshop blend process. 2016.

Both quantum superposition (where a single particle is apparently in two places or has a mixture of states simultaneously) and quantum entanglement (which involves more than one particle) along with other counterintuitive properties of the quantum world arising from the Copenhagen interpretation of the experiment are discussed in the next chapter. The subsequent chapter looks at the theories of David Bohm who took a different view and was the first physicist after Einstein and de Broglie to seriously tackle the conceptual difficulties of the Copenhagen interpretation by seeking an ontological understanding that challenged the anti-realist Copenhagen stance (Ananthaswamy 2018:149).

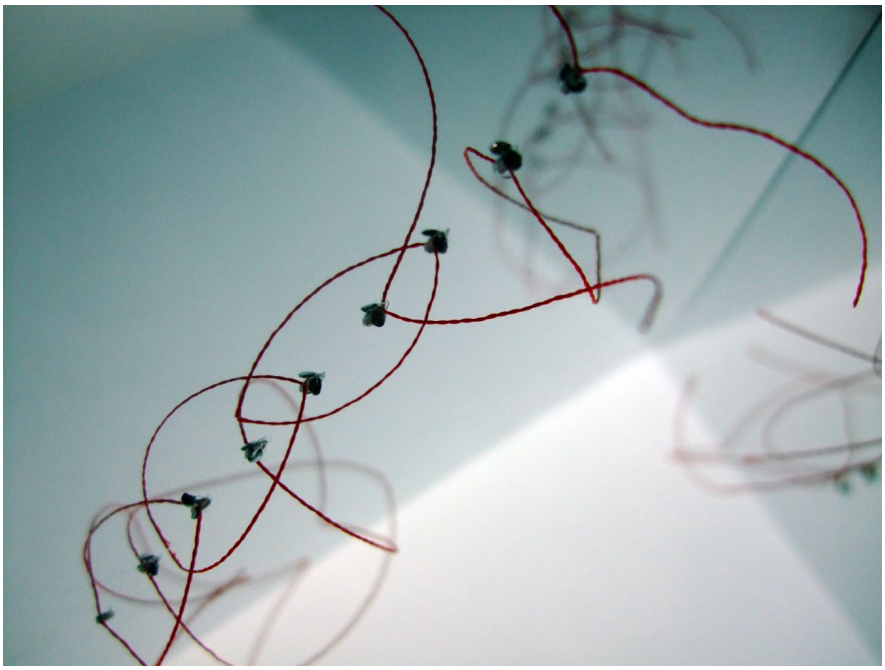


Image 78: Two-way mirror with drilled holes, red thread. 2015.

Part III—The Science of Light: Unravelling Threads of Influence

Chapter 6
Patterns of Entanglement—Diffraction and Moiré

Textile Notion #7: Entanglement

Entanglement: Entanglement is a natural state for thread when it is not held in place by another structure. It derives from *tangle* meaning a snarl of threads, to twist or interweave in such a manner as not to be easily separated (from the Old English of the 1600s).

The textile metaphor in the term *quantum entanglement* aids and concretises understanding of this counter-intuitive quantum concept that is difficult to imagine. The quantum states of two or more particles can become linked to each other. Even though the individual objects are spatially separated, a change in the state of one entity *instantaneously* (i.e. faster than the speed of light) results in a change in the state of the other. No matter how far apart they are in the universe, they remain entangled. This non-local effect was initially purely theoretical and Einstein could not accept anything travelling faster than the speed of light. Nonetheless, physicists have now verified the theory, for example by transmitting and successfully recording the instantaneous change in the state of the entangled photons 144 kilometres (89 miles) between La Palma and Tenerife in 2007.

Quantum physicist, Carlo Rovelli writes in *Helgoland*, "Entanglement is the strangest of all strange quantum phenomena, the one that takes us furthest away from our old understanding of the world…[and] in a sense weaves the very structure of reality" (2021:81).

The red threads in Image 78 opposite provide a literal expression of entanglement. They pass through holes that perforate the mirrors, linking them together. The threads then become entangled with their own reflections, which entangle with yet more reflections in the second mirror. The reflected threads and holes co-exist virtually, visually combining with the real ones. The portions of the threads that pass through the holes and behind the mirror are unseen but still exist, and, their reflections suggest their trajectories. In this way,

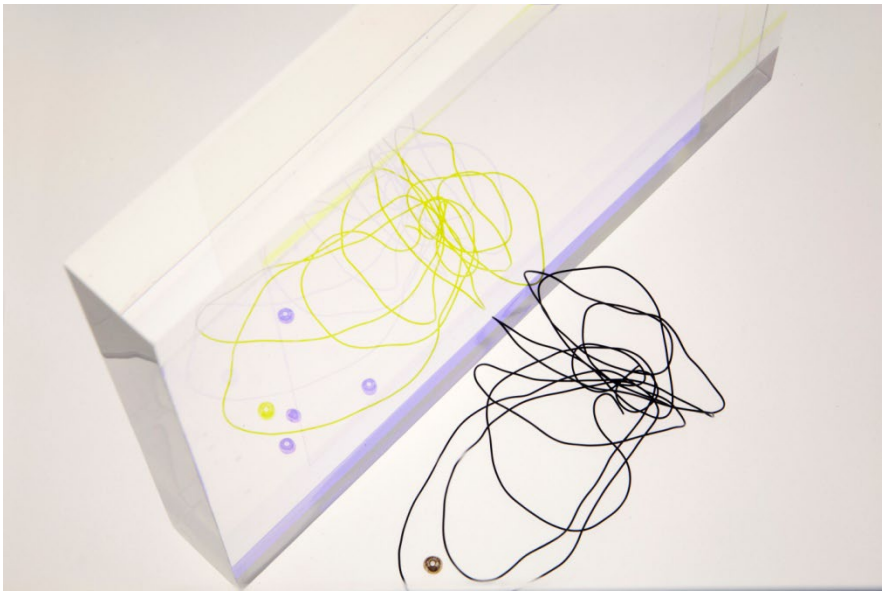


Image 79: *Unfolding Light and Space #1. Detail view.* Prisms, two-way mirror, wire, gold beads, LED panel. Photograp Ibolya Ferher. 2015.

the dual opposites, virtual/real and seen/unseen are entwined, existing in the same space. The dualities of full/empty are also evident as the holes appear as black particles suspended in space and seem to have substance, but, being holes, they are, in reality, empty.

The two mirrors are perpendicular to each other and create a three-dimensional space with the 'floor'. However, the perception of length and depth is confounded by the reflected reflections, introducing entwined perspectives—extending what one sees beyond the boundary of the space framed by the mirrors. In this way, the fixed point perspective (originating from Renaissance art) is challenged.

Entanglements

As seen in Chapter 5, several themes arise from the two-slit experiment and each theme is interwoven with another—they are entangled, contingent on one another. The current chapter tugs at the threads of these entanglements by looking at them through the lens of Karen Barad's reading of Niels Bohr's quantum mechanics and then discusses New Materialism. Barad's philosophy-physics is firmly inspired by their comprehensive examination and clear understanding of Bohr's theories based on his interpretation of the two-slit experiment. Barad developed a diffractive methodology from Bohr's theories, proposing an ontoepistemological account of reality (2007:43-44). They describe the qualities and process of the entangled nature of reality in their book, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning,* writing,

> To be entangled is not simply to be intertwined with another, as in the joining of separate entities, but to lack an independent, self-contained existence. Existence is not an individual affair. Individuals do not preexist their interactions; rather, individuals emerge through and as part of their entangled intra-relating (Barad 2007:ix).

Early in the research, it became apparent that quantum physics had a rich potential to convey pertinent meaning across other fields. This intuition was later substantiated by the realisation that quantum physics offered vehicles to provide rich insights, not only into the nature of light and reality but also to question prevailing perceptions and thinking. I concur with Barad who argues that quantum physics both poses counterintuitive challenges to the modernist worldview (2007:6) and opens up possibilities for new non-dualist thinking, asserting that "Quantum theory leads us out of the morass that takes absolutism and relativism to be the only two possibilities" (2007:18).

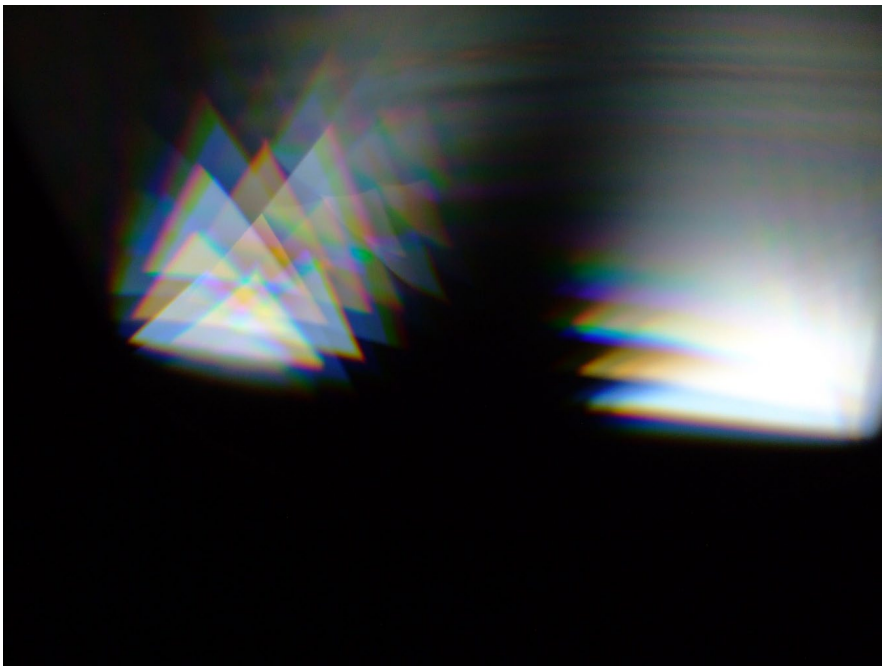


Image 80: Cut black paper, diffraction grating, LED light. 2015.

Barad's viewpoint lends weight to this research's underlying threads, intuitions and artistic discoveries, including indeterminate boundaries, wave-particle duality, moving beyond Cartesian subject/object dualisms and the simultaneous overlay of multiple viewpoints, all of which are entangled in the investigations, artworks and installations. As an example, Barad describes how intra-action permits a dynamic, interconnected relationship across dualisms and becomings. They write,

> time and space, like matter and meaning, come into existence, are iteratively reconfigured through each intra-action, thereby making it impossible to differentiate in any absolute sense between creation and renewal, beginning and returning, continuity and discontinuity, here and there, past and future (2007:ix).

Barad's Intra-action

In the double-slit experiment, the mysterious relationships between particle, wave and apparatus demonstrate that the natures of matter and light are entangled. To frame and develop their thinking on entangled relationships, Barad formulated the term *intra-action*, writing, "The dynamics of intra-activity are explicitly non-linear, causal and nondeterministic" (2007:240). Intra-action is key to Barad's theories; however, it is not the same as interaction. *Inter* of interaction is a prefix from the Latin meaning between, among and in the midst of, and, when together with the verb to act, means to do things with others. With interaction separate, individual agencies exist prior to their interaction and continue to maintain a level of independence from each other (2007:33). On the other hand (also from Latin), *intra* means interior, on the inside, from within. When coupled with the verb to act, it forms Barad's neologism 'intra-action'. They argue that distinct agencies do not precede but emerge or materialise through their intra-action—the ability to act, behave, or perform emerges from *within* the relationship, not outside of it (2007:33).

From a human perspective, anthropologist Tim Ingold finds Barad's intra-action to be limited as it "fails to convey the essential feature of mutual responsiveness" and correspondences which he defines as living together in difference (2022:6).

Material Practices

There is also a shared enthusiasm for material practices. In Barad's case, rather than relying solely on theoretical physics, they embrace the material practices of experimental physicists, including the two-slit experiment, to develop their ideas. On the other hand, the current research intrinsically centres on physical material practices, firstly, through the series of hands-on material investigations (in particular, examining the potential for specific optical materials including exploring the property of diffraction by using diffractive

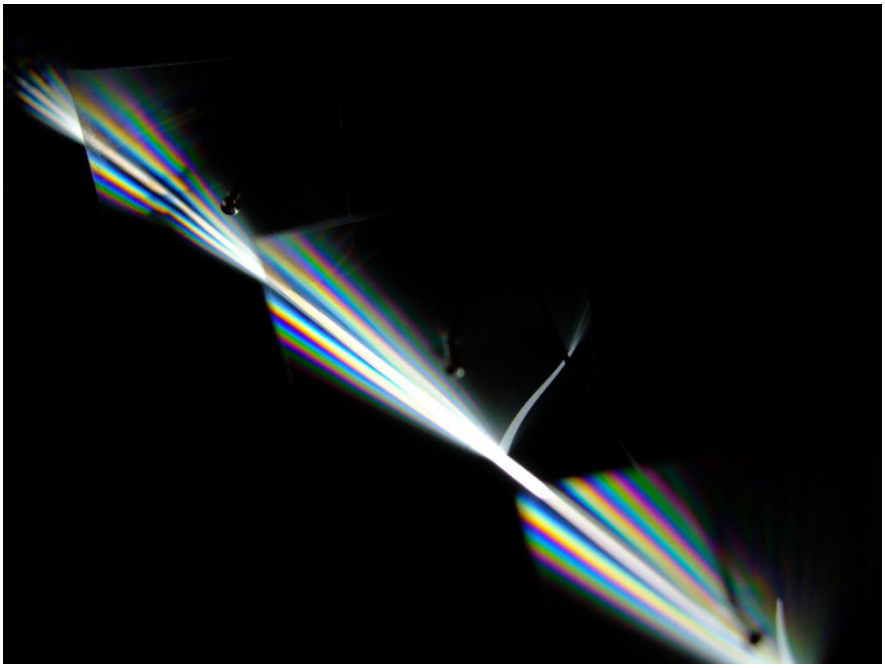


Image 81: Black paper cut with one slit, diffraction grating, LED light. 2015.

materials to describe quixotic quantum properties); secondly, through using these materials (more commonly found in a science laboratory than an artist's studio) to express the themes arising from the quantum properties of light through the creation of artworks. There is a shared appreciation for diffraction, one of the most engaging and lively quantum properties and it is the primary device that overlaps both Barad's work and the artwork created for this research. This creates effects that enable the visual expression of paradoxical quantum qualities such as indeterminism and the entangled nature of subject and object, giving these concepts physical substance.

Diffraction

Diffraction is a fundamental quantum phenomenon central to the two-slit experiment that indicates the wave property of light and is unique to wave behaviour (Barad 2007:28). We can experience it in our everyday world and, therefore, it transcends both the quantum and classical realms and is eminently suitable to bring quantum ideas to material and visual form. It is worth remembering here that the two-slit experiment itself is a diffraction grating with only two slits (Barad 2007:73)—equally, a diffraction grating is equivalent to numerous double-slits simultaneously. Barad notes that interference patterns are a distinctive mark and general feature of quantum behaviours resulting from superpositions and points out that "Superpositions challenge our classical metaphysical view of the world" (2007:269). Barad explains how diffraction patterns are themselves a matter of entanglement and observes, "Diffraction not only brings the reality of entanglements to light, it is itself an entangled phenomenon" (2007:73). They argue that diffraction is about understanding differences and, philosophically, it is the entangled nature of "differences that matter" (2007:36, 90). They say, "differentiating is not about Othering, separating, but on the contrary, about making connections and commitments. So the very nature of materiality itself is an entanglement" (cited in Dolphijn & Tuin 2012). Significantly, for Barad, difference is tied up with ethics and responsibility, i.e. the ability to respond.

Barad's theories build on Donna Haraway's feminist academic discourse. When theorising about knowledge and thinking, Haraway suggested that diffraction can serve as a valuable counterpoint to reflection to move away from a reductive language that assumes rigid connections between signifier and signified, word and objects (Haraway 2004). As a critical strategy, diffraction allows for one text to be read through another by interweaving the threads and entanglements and allowing them to affect the others. As Iris Van der Tuin explains, "Diffraction is meant to disrupt linear and fixed causalities and to work toward 'more promising interference patterns'" (2011:26). Diffraction is a pillar of Barad's theories; it is so essential to their thinking that they developed a 'diffractive methodology' which was employed to write their book, *Meeting the Universe Halfway*. They note that

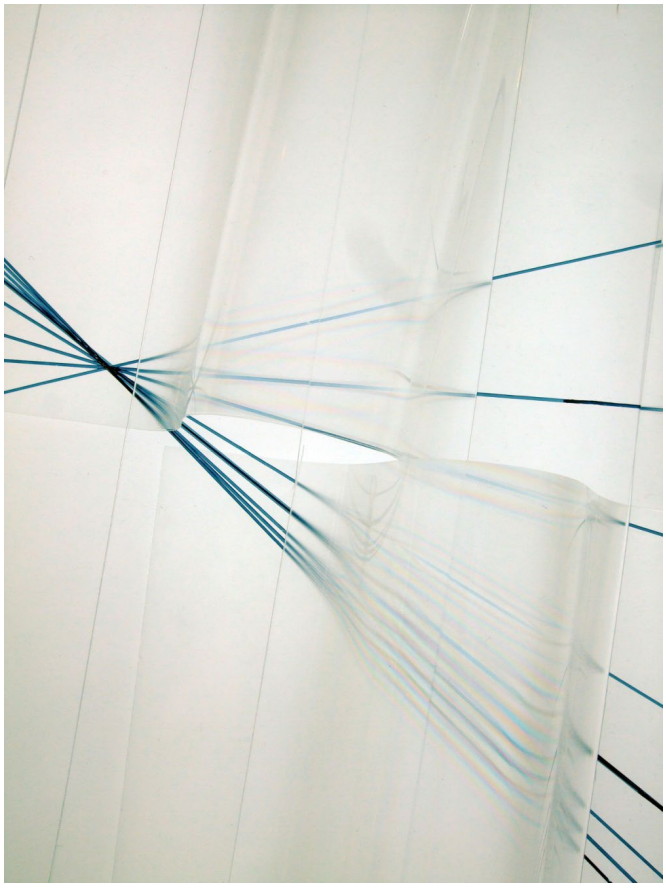


Image 82: Black ink drawing on paper, diffraction grating. 2017.

diffraction is the overarching trope for the book (2007:70) and state that the book itself functions as a diffraction grating, "illuminating important material differences, relationalities and entanglements in the lively dance of mattering" (2007:37).

Diffraction is a highly effective methodology for cutting across or bridging dualisms, what Barad calls "cutting together-apart". They write extensively on the subject of diffraction and, in their paper, *Diffracting Diffraction: Cutting Together-Apart,* they observe:

> [D]iffraction is not only a lively affair, but one that troubles dichotomies, including some of the most sedimented and stablized/stabilizing binaries, such as organic/inorganic and animate/inanimate. Indeed, the quantum understanding of diffraction troubles the very notion of *dicho-tomy* - cutting into two - as a singular act of absolute differentiation, fracturing this from that, now from then (2014:168).

Ingold relates this to his concept of 'interstitial differentiation' where "splitting apart and mingling together are two sides of the same coin" (2022:265).

There are many correspondences in the current research to the many themes embedded in Barad's writing; many were coincidental. In this research, there was a deliberate decision to physically explore Barad's notion of "cutting together-apart". This resulted in a series of material investigations where strips of diffraction grating were woven in loose folds through cuts made in black ink drawings of lines on white paper (see Image 82). This created waves of diffraction grating that curved away from the surface of the drawing. The lines are disrupted by light passing through the angled diffraction grating, their singularity interrupted so that each no longer appears as an individual line; they appear to fan out and multiply, softly revealing the seven spectrum colours that are always concealed within white light. White light cannot be assigned a single wavelength, as it is composed of wavelengths of different colours and has a range of 400 to 700nm—even though we are not normally aware of these colours with our everyday eyes, they are always there. The binary of black and white becomes a multitude of colours which returns to its monochrome state as the diffraction grating meets the paper again and the diffracted coloured lines re-gather, one with another, the dualistic black and white once again.

Subject/Object

In developing their theories of agential realism and intra-action, Barad was "looking for a more complex topology than a kind of level playing field of objects and subjects" (cited in Kvinder 2012:12), so they used Bohr's quantum mechanics to examine and apply their understanding of diffraction to move towards a reconfiguring of subject/object relationships by rejecting an absolute exteriority and absolute interiority of things. Barad argues that intra-action challenges and reworks traditional ideas of causality, individual

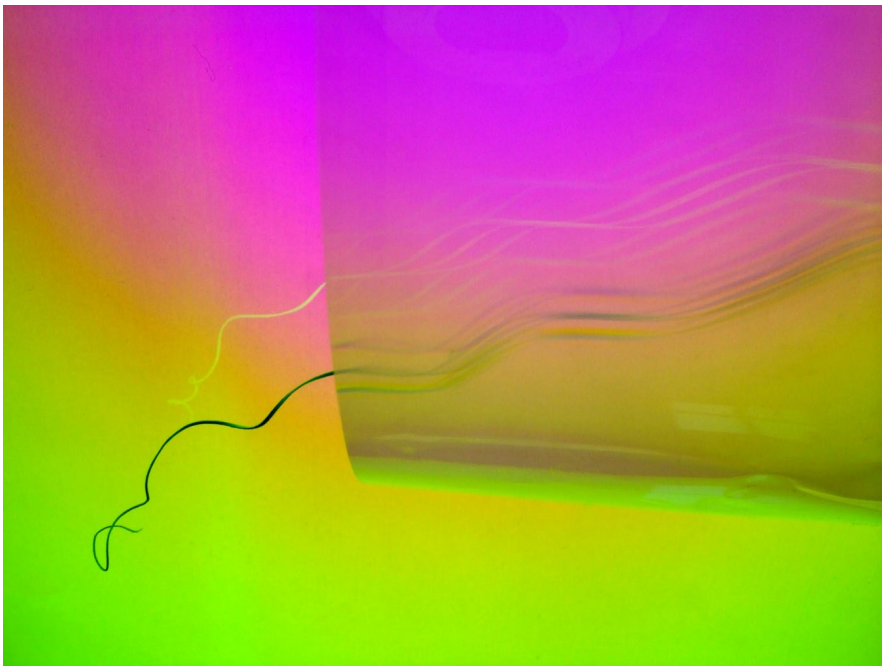


Image 83: Dichroic film, diffraction grating, thin sliver of black paper, LED light. 2015.

agency and subject/object dichotomies and, as in this research, also calls fixed or determined borders and boundaries between subjects and objects into question (2007:33). Challenging boundaries and the dualities of exterior/interior and subject/object are recurring features of the artworks.

Beyond this, Barad argues that intra-action helps us think about simultaneity and offers new possibilities for thinking about our relationships with matter, with nature and relationships between people. Barad's inferences are wide-ranging, as they explain:

> Indeed, the new philosophical framework that I propose entails a rethinking of fundamental concepts that support such binary thinking, including the notions of matter, discourse, causality, agency, power, identity, embodiment, objectivity, space and time (2007:26).

One of the examples of quantum weirdness revealed by the double-slit experiment is the observer's effect on the outcome. This was described in the previous chapter and it demonstrates the mysterious way that the experimenter/apparatus, subject/object are entangled—there can be no such thing as a detached observer. Bohr argued against the Cartesian premise that there is an intrinsic boundary between subjects and objects (Barad 2007:154, Juelskjær & Schwennesen 2012:19). There is no definite way to distinguish between the observer and the object and Barad declared that "*No inherent/Cartesian subject/object distinction exists*" (2007:14) [their italics]. Barad learnt from Bohr that "the belief in an inherent fixed Cartesian distinction between subject and object is an unfounded prejudice of the classical worldview" (2007:359). This calls to mind Capra's Systems View, where there is a shift of perspectives from objects to relationships. In the mechanistic view, the world is a collection of objects that interact and their relationships are secondary, whereas, in the Systems View, objects themselves are networks of relationships and, in turn, are part of more extensive networks where the relationships are primary.

The artworks demand more of the viewer than a simple viewer/artwork interaction. To experience the fullness of the work, viewers are asked to act and react to what they see by adjusting their postures to alter their view, thereby changing the visual information they receive—the whole body becomes engaged in viewing the works. The viewer activates the work by seeing different views depending on viewpoint—seeing one thing from one position—and something different from another. All possible views exist in the work at all times—how you see it depends on where you see it from; the other states still exist, even if you don’t see them at a particular moment—the viewing position can reveal only one state at one time. In this way, a sense of certainty about the nature of reality is questioned. The meaning gained from the works is not just intellectual or philosophical, it

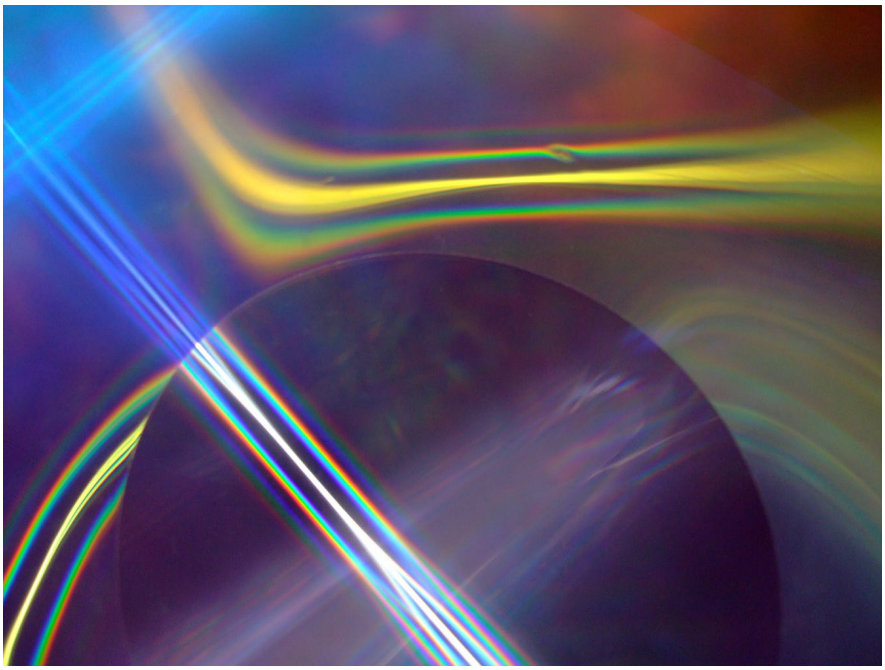


Image 84: Black paper cut with one slit, diffraction grating, dichroic film, LED light. 2019.

is primarily obtained on an experiential level and impacts viewers' internal perceptions. As the entangled themes are more implicit than explicit, each person is free to make their own interpretation or impression when looking at the works.

New Materialism

Although the motivation for this research evolved from an investigation into the nature and properties of light that includes an enquiry into the physical properties of optical materials, it was not embarked upon from a new materialist standpoint. Nonetheless, it finds itself in alignment with many of the positions of new materialist thinking. Barad was one of the theorists whose work initiated new materialism, an emerging cross-disciplinary trend that offers alternative approaches to agency, nature and social relationships, thereby stimulating questions about our place in the world and our relationship to the environment. The term new materialism was coined by Manuel DeLanda and Rosi Braidotti in the 1990s and, although there is no single definition, some distinctions have emerged. As defined by Christopher N. Gamble *et al*. (2019:112), these include Vital New Materialism, which evolved from the works of Gilles Deleuze and Performative New Materialism, which questions the separation between humans and matter and is aligned with the writings of Barad.

New materialisms are generally characterised by a shift from epistemology to ontology; however, as real things do not exist independently of knowing, both are "co-implicated and mutually constituting" (Gamble *et al*. 2019:122)—Barad created the term ontoepistemological to express this entanglement (2007:44; 2007:185). As previously described, Barad's viewpoint is based on their novel reading of Bohr's quantum mechanics, where both light and matter are indeterminate and not entirely separable from the apparatus used to observe them. From this, new materialism views matter (both its properties and actions) as primary, challenging the historical perception that matter is "passive, devoid of meaning and discretely self-contained" (Gamble *et al*. 2019:112). Hence, it questions both the mechanistic perspective of Francis Bacon and Isaac Newton and the dualism of René Descartes, where matter and spirit are seen as being distinct and separable.

New Materialism and Art

Dorota Golanska (2018) observes that making art through a new materialist lens, rather than in a largely representational way, is primarily focused on an engagement with materials. Citing Barad, Golanska says that art, seen from a new materialist viewpoint, is an entangled process of becoming and that it,

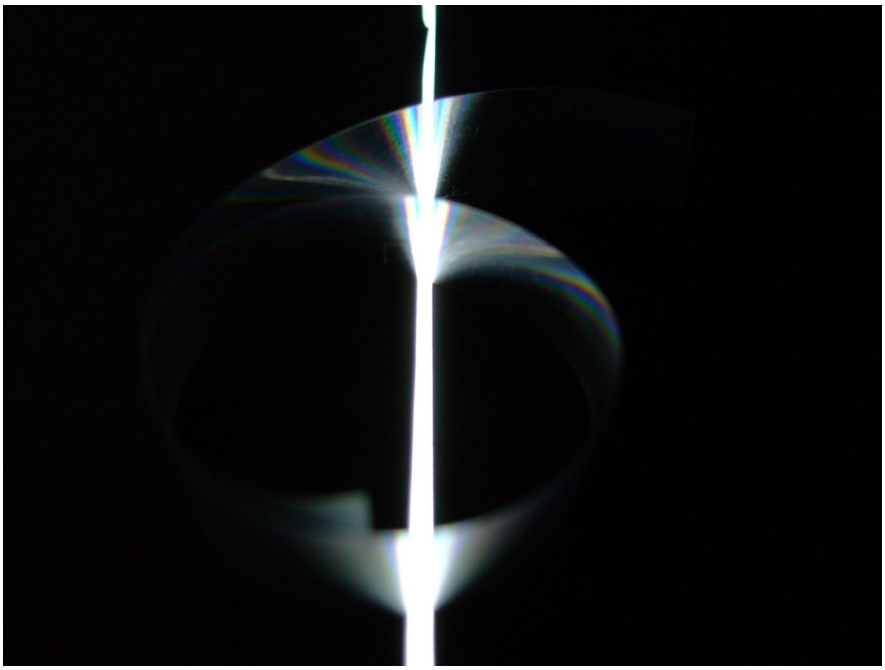


Image 85: Black paper cut with one slit, diffraction grating, LED light. 2015.

> [S]hould be understood as an intra-active becoming, where the examination of "intra-activity" lets us grasp, in Karen Barad's view, how subject and object emerge in the process of complex "material-discursive" entanglement, and how fluid, temporary, and porous boundaries of these entities and processes remain. Accordingly, the contours of the object and the subject of knowledge are contingent on their relations, never fully defined, always moving, always becoming. And the becoming is equally relational—always affecting and being affected by other becomings and encounters with other bodies and forces (2018).

This is true of the artworks created for this research, where their material qualities are not emphasised but are also entangled—the boundaries are indeterminate, the subject/object relationship is questioned and (even though an artwork may be physically static) the experience of them is dynamic, shifting and not fixed. Art-making is intrinsically concerned with both the interpretation and manipulation of materials and inventing new objects, allowing artists not only to question matter but also interrogate our relationships with the world. In this project, the investigations into and employment of chosen materials demonstrate that matter is performative (as Barad's agential realism assumes), is intra-active and is "not immutable or passive" (2007:151). And, as with the current research, "new materialists routinely emphasize how matter is 'alive,' 'lively,' 'vibrant,' 'dynamic,' 'agentive,' and thus active" (Gamble *et al.* 2019:111) and is transformed by each encounter, "ceaselessly forming novel entities and/as relations, thereby also ceaselessly generating novel possibilities and impossibilities that did not exist already" (Gamble *et al.* 2019:114). In this enquiry this is important in fulfilling the aim of influencing perception via the Reticular Activating System of the brain.

The art practice has innovated new aesthetic applications for the materials, presenting novel forms and offering experiences that both enact and illuminate the themes highlighted by both new materialist thinking above. The artworks playfully engage the viewer in experiencing subject/object entanglements, unfixed boundaries and unified dualities. New materialisms question the dualisms of nature/culture, mind/body and human/non-human. In this project, philosophical considerations such as these (disrupting a variety of dualities) are addressed theoretically and physically through an engagement with matter. Nicholas Leonard observes that,

> [R]ather than addressing reflective binary thought in artworks, such as a political cartoon, new materialism investigates how engaging with the matter of an artwork can produce new relational differences.

He later continues, “[B]y engaging with art within the new materialist framework, art is not a symbolic binary statement but a provocation to change the becoming of the world” (2020).

Image 86: *Unfolding Light and Space* #5. Installation view. Two-way mirror, wire, black rhinestones, button, tempered metal marble, LED panel. Photograph Ibolya Ferher. 2015.

As is true with the works created for this enquiry, Golanska observes that art functions on both the material and representational levels simultaneously through a new materialist analysis. As a result and based on Barbra Bolt's enquiry into representational and performative art (2004), she suggests differentiating between a "work *of* art" (which she defines as a process of becoming that is capable of movement and creation) and an "artwork" (which she suggests is a passive vehicle for artists' ideas). Under the above distinction, the works created for this research are active, therefore, they could be defined as works *of* art. However, although they are active and performative, for brevity, they are mostly referred to as artworks rather than as works of art throughout this thesis.

Reflection vs Diffraction

Barad identifies diffraction as an alternative methodology to reflexive, representationalist practices and makes a philosophical comparison between the merits of diffraction over reflection. They propose a diffractive methodology (2007:86-94; 2014:168-187) for their discursive practice that counters the reflective methodology found in representationalist scholarship (cited in Revelles Benavent 2010:83). This allows for performative practices (of doings and actions) rather than a focus on reading one thing against another (2007:28 2007:89-90) and they say, "I argue that a diffractive methodology is respectful of the entanglement of ideas and other materials in ways that reflexive methodologies are not" (2007:29). The artworks for this research entangle ideas, materials and textile thinking.

In science, diffraction and reflection do not co-exist; diffraction excludes reflection, so you either have diffraction, or you have reflection. Reflection and diffraction represent two different ways of thinking and approaching the world. Barad argues that historically, reflection or reflexivity has been privileged over diffraction and advocates an about-turn from reflexivity to diffraction because diffraction, as a material-discursive phenomenon, offers greater possibility for the relationship between discursive practices and the material world to be addressed in new ways. Barad relates this to optics, closely examining and contrasting the qualities of the two comprehensively analysing the differences in the two modes of thinking (2007:86-94; 2009) privileging diffraction over reflection. Reflection is a property of classical physics (where there is a faithful mirrored point-to-point correspondence) and diffraction, "which does not concern homologies, but attends to specific material entanglements" (Barad 2007:88) is more akin to the quantum realm.

This research aims to disrupt dualisms and therefore presents the view that dualisms of diffractive and reflexive practices both have merit; it is not a matter of either/or. Although diffraction presents a new view, it is not expedient to sideline reflection as both offer different but equally valid views. Art permits the physical co-existence of both diffraction

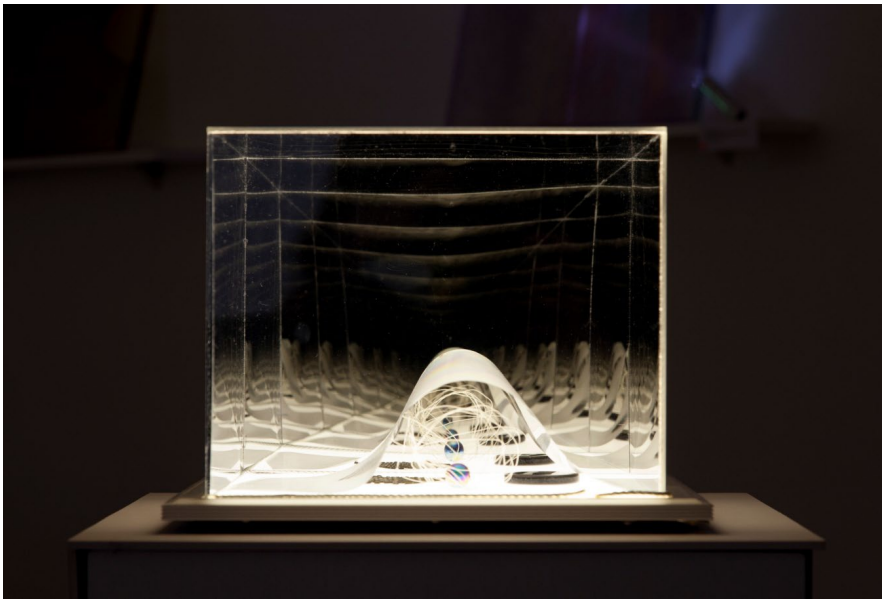


Image 87: *Unfolding Light and Space* #5. Installation view. Two-way mirror, wire, black rhinestones, button, tempered metal marble, LED panel. Photograph Ibolya Ferher. 2015.

and reflection simultaneously, therefore, embracing both modes of thinking with no requirement to prioritise one over the other. In this research, the properties of both are closely examined through the material investigations and are juxtaposed into the artworks, where they can be read literally or metaphorically. For example, one such work, *Unfolding Light and Space #5,* intertwines reflection and diffraction. One sees a mirror box lit from below that encapsulates everyday particle-like objects—a large button, beads, a marble, a tangle of wire and diffraction grating. The edges of dark objects seen through the diffraction grating are diffracted and distorted, unfolding to produce a series of subtle rainbow-hued penumbras that echo the shapes of the dark objects, which is a direct example of diffraction in action. The half-silvered mirror affords a puzzling experience of reflection and transparency as it exhibits both properties simultaneously and unfolds the interior space towards infinity which would not be possible without the mirrors' reflective properties.

In science, the primary purpose of a diffraction grating is to separate the wavelengths to reveal the colours making up light in spectrometry. In this piece, coloured virtual 'shadows' around the 'particles' have indeterminate, multiplied boundaries—ephemeral, coloured filigree strands fan out from the thin wire. However, the soft pastel colours one sees are an illusion. Apart from the tempered metal of the small sphere, in actuality, there are no coloured objects—there are only monochrome elements inside the cube: the whiteness of the light, the softer white of the diffraction grating, the greyness of the wire, the blackness of the grid of spots and the black 'hole'. The pastel-coloured auras one sees are generated by the diffraction effect that unravels the spectrum wavelengths that are typically tightly folded inside white light. They are revealed where the light butts against the edges of the black and grey elements in the box—here, diffraction disrupts the edges creating indeterminate and shifting borders by unveiling and unfolding the delicate beauty hidden within the whiteness of light. The wave nature of light is revealed through diffraction; moreover, wave/particle duality is made explicit and questions boundaries.

In a spirit of inclusion and unifying dualisms, this work combines and embraces both modes of thinking (reflection and diffraction) equally. Diffraction does not stand in opposition to reflection; instead, they are entangled, producing new possibilities and new aesthetic possibilities. In addition to illuminating the opposing philosophical considerations listed by Barad (2007:89), each property contributes distinctive aesthetic qualities—the crisp, almost clinical, point-to-point correspondence of reflection (aligning with classical physics), juxtaposed with the layered, soft, dissolving, ambiguous nature of the wave-like interference of diffraction (aligning with quantum physics).

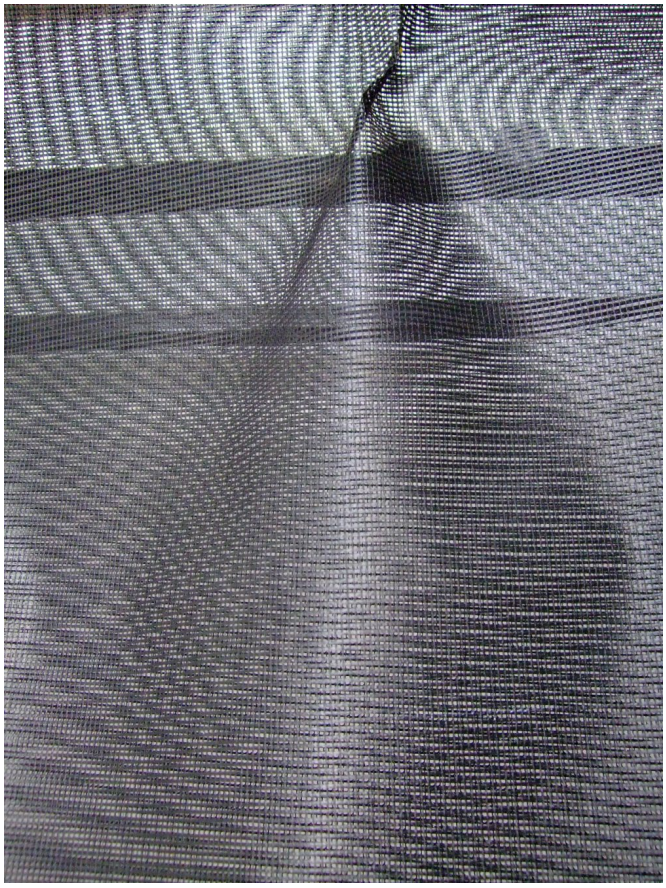


Image 88: Two layers black screen fabric, black paper strips, pin. 2016.

The motivation for bridging the dualities and giving both diffraction and reflection equal status and validity evolved from a position of inclusivity. Not an "either/or" binary, or even "and and both", but from artist, Roy Ascott's syncretic position of "both both/and and either/or". Ascott, uses the term 'syncretism' to define an alignment of extreme differences and binary oppositions. He explains,

> In the syncretic context, extreme differences are upheld but aligned such that likeness is found amongst unlike things…the power of each element enriching the power of all others within the array of their differences…Standing in emphatic distinction to binary opposition, syncretism is a process between different elements, the in-between condition of 'being both' (2005).

The distinction between the two optical metaphors, diffraction (the phenomenological feature of waves and interference patterns) and reflection (a relatively faithful mirroring of the world) also has resonances with Bohm's observations of the differences between the simple point-to-point correspondence in photography and the enfoldment of information about the whole in every part of a holographic plate (see next chapter). This information exists in a complex series of moiré interference patterns (Bohm 1985b:11; Bohm & Peat 2000:175).

Moiré—Interference Effect

Moiré is a larger scale, optical interference effect than diffraction that challenges visual perception and is akin to the phasing and superposition of frequencies that form interference sonic effects in music (Nicolai 2010:1; Bateson 2002:74). It is the everyday experience of entangled interference patterns which are created when two identical copies of a grid or grating are superimposed and are slightly misaligned to be differently oriented, phased or angled, producing dynamic, topological transformations. Even if the slippage between the layers is minute, the transformations produce dramatic and surprising visual interferences—with moiré, a small displacement leads to a large effect. Consequently, scientists use moiré to their advantage to magnify tiny differences when making microscopic measurements; it is also used to solve problems in optics, stress analysis crystallography and mathematics.

Interference requires some 'other' as there needs to be something else to interfere with—even if it is some other part of the same striated or gridded whole that is folded over and interacting with another layer of itself. The exception to the requirement for another is at the quantum level. In the two-slit experiments, a single particle passing through the apparatus appears to interfere with itself because there is no other particle to interfere with (see Chapter 5).

Image 89: Two layers of mesh fabric, masking tape, tempered metal marble, pin. 2016.

The optical moiré dance seen through the folds of a net curtain, demonstrates interference effects at a scale within the human visual range. The grids formed by the woven threads in cloth are, in effect, oversized double-axis diffraction gratings. The change of scale from 13,000 lines per inch in the diffraction grating used in the artworks to tens of threads per inch in woven cloth allows us to experience the interference patterns at a human scale. In Image 89 opposite, the layered grid of the warp and weft is disrupted, the moiré patterns creating a meandering topological surface that shifts with every movement. The striations of the translucent striped fabric are clearly evident; however, when overlaying each other, the graphic orderliness of the stripes becomes disrupted by the meandering optical dance of the moiré patterns.

Scale (i.e. changing the size of one object in relation to another) is a useful device that emphasises changes in the relationship between the object and the viewer. Furthermore, a change of scale directs our attention and influences what we see, permitting other discoveries and meanings to emerge. At this scale, the striations in the cloth exist far enough apart not to cause light to diffract (as it does with diffraction grating); however, it permits interference patterns to be directly sensed and experienced. In this way, a moiréd fabric bridges the opposition of the smooth and the striated, as described by Deleuze and Guattari in *A Thousand Plateaus* (2013:551-553).

Moiré in Art

Moiré is taken to a grand scale with the *Double Aperture Moiré Wall* installation in the final exhibition where the displacement of the grid pattern of the two layers of plasticised fabric create a dynamic moiréd surface. However, moiré is not commonly seen in art, it is used more often in design where it is a tool for adding excitement, depth and movement. Nonetheless, Olafur Eilasson has incorporated moiré into some of his works. In 2004, he showed three installations that exhibited moiré effect, *Triple ripple, The inverted panorama house* and *The uncertain museum*. Each consisted of glass discs coated with concentric rings of mirror coating driven by motors and lit with HMI lamps.

The inverted panorama house is the most complex of the three, also composed of stainless steel, wood, projection foil, colour-effect filter glass and spotlights and a fabric screen. Light from a spotlight is reflected, obstructed, and filtered by the rotating glass forms to produce a complex interplay of reflections and shadows, reminiscent of Moholy Nagy's *Light Space Modulator* of 1929. As they turn, their shadow patterns create moiré effects.

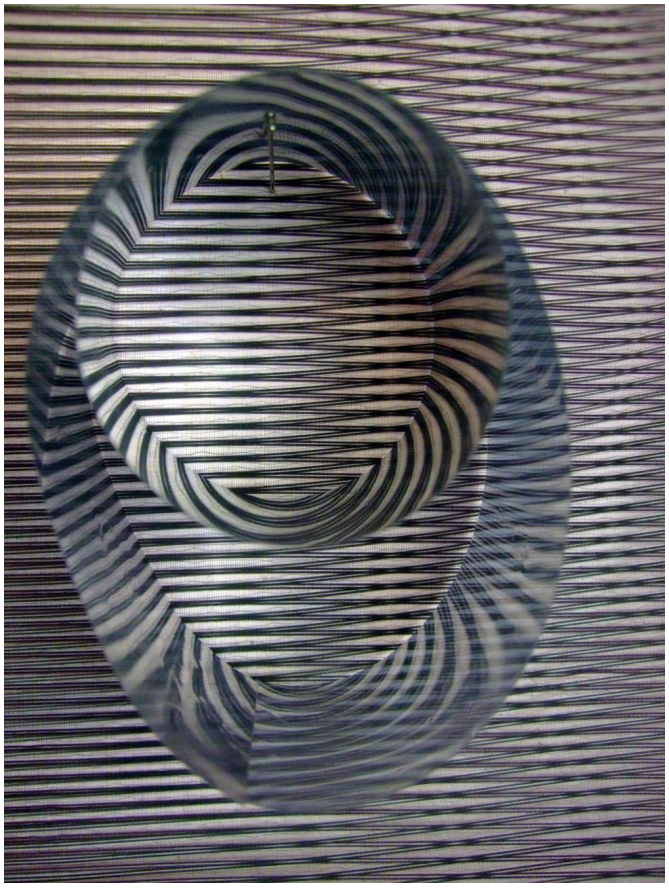


Image 90: Striped translucent fabric, two-way mirror film, pin. 2016.

Figure 12. *The inverted panorama house*. 2004. Olafur Eliasson. Photograph Günter Lepkowski.

Subsequent to pieces like *Walk through wall* (2005), *Eye see you* (2006), *Waterfall machine* (2009) and *Colour reflection amplifier* (2018), Eliasson revisited moiré more fully in the Nel tuo tempo exhibition at the Palazzo Strozzi in Florence in late 2022. *Under the weather* dominated the courtyard entrance to the palazzo. The horizontally installed, elliptical steel frame is wrapped in bands of recycled polypropylene strapping, a printed textile is mounted behind and is lit with mono-frequency lights. As the viewers move beneath and around it, the moiré patterns dynamically shift in response to their movement and eliciting "moiré effects that destabilise your sense of equilibrium" (Eliasson 2022:10). Eliasson (2022:101) makes the point that, as with his artwork, *Beauty* (1993), the experience is individual and subjective.

Figure 13. *Under the weather.* 2022. Palazzo Strozzi, Florence. Olafur Eliasson. Photograph Peta Jacobs.

Your view matter (made in collaboration with Metapurse) uses virtual-reality augmented reality and blockchain technologies and takes the users into an interactive experience into, and through, a series of six geometrical room spaces. The walls and ceilings of five of the 'rooms' are formed of Platonic solids and the sixth a sphere. Each is adorned with dynamic moiré effects so that the viewer wanders through while they examine these scintillating moiré environments from within. The viewer is integral to the artwork, Eliasson (2022) observes, "*Your view matter* enlists not only vision but also the movement of your heads and bodies to create the work – your animated body–brains". The materiality of the views' bodies meets the immaterial virtual reality world.

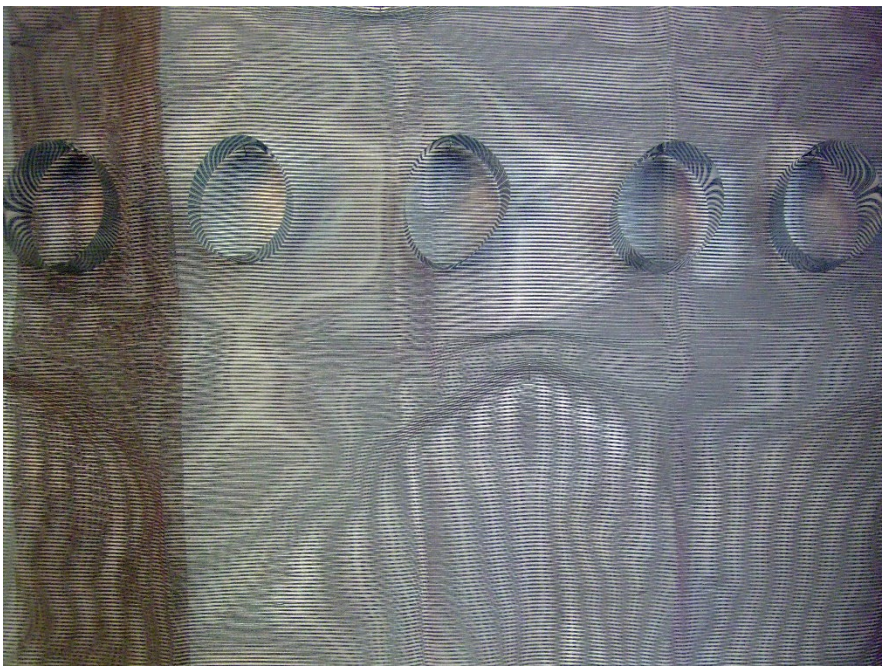


Image 91: Striped translucent fabric, two-way mirror film, pin. 2016.

Whereas the investigations into moiré in my project are drawn from an exploration of quantum light's interference properties, Eliasson's focus is phenomenological. With moiré, he invites the viewer to become aware of their bodies, minds and emotions, how they see and how they move in response to the art. He asks, "When that moiré effect emerges in a new artwork using virtual-reality technology, with novel consequences for how we experience space and see ourselves seeing? In short, what emerges from these spatial transformations?" (Eliasson 2022:10).

Moiré is a large-scale interference pattern akin to diffraction, the change of scale allows us to experience the nature of interference, challenges visual and spatial perception and providing an experience of movement. Diffraction is a wave property of light that demonstrates that the experimenter/apparatus, subject/object or viewer/artwork are entangled (Barad 2007:14). However, moiré is an illusory optical effect as the rippling patterns do not actually exist—they are formed and perceived through the brain's perceptual processes.

Two examples follow to discuss the role of moiré in this research. Firstly, the *Double Aperture Moiré Wall* in the final exhibition. It spanned the whole gallery and was enveloped in layered fabrics that created a moiré effect. Although the wall was static, the moiré patterns dynamically danced across it as the viewer approached. As with Eliasson's works, the act of seeing and visual processing are key elements—as viewers shifts their vantage points, they 'activated' the works. In addition to the apprehension of space being tested and perception challenged, what viewers perceive invites many questions, such as the edges of things which are unfixed and appear to be more than one thing simultaneously.

Secondly, exploiting and magnifying the (usually unwanted) moiré effects in lenticular photography led to the creation of static prints that are able to kinetically generate dynamic moiré vortexes. These artworks articulate Bohm's theories of holomovement (the process where the undivided wholeness of the implicate order underlying reality is in a perpetual process of flux and becoming see Chapter 7). The kinetic vortex shifts as viewers move position, introducing the sensation of movement despite their static form—once again questioning a fixed position (see Chapter 9). The apprehension of space is tested, perception is questioned, the edges of objects are unfixed and things appear to be more than one thing simultaneously.

*

Image 92: Two-way mirror film, coiled spring, LED light. 2016.

Karen Barad offers a model of philosophical/cultural interpretation of quantum physics. Both examining Barad's writings and looking at the new materialist frameworks serve to support the themes and ideas that underlie this enquiry and are embedded in the artworks and investigations. Drawn from quantum physics (such as entanglements, superposition, simultaneity and the interconnectedness of the observer and the observed), both Barad and this research challenge Newtonian mechanistic and Cartesian dualistic thinking.

Barad developed a diffractive methodology and proposed ideas of intra-action and agential realism; their approach to diffraction is more than metaphoric, it is methodological. However, the approach in this research also attends to the physical properties of diffraction, where the material engagement with diffractive materials provides a visceral and visual experience of this phenomenon and the ideas it encapsulates. Many of the inferences that can be drawn from a study of quantum physics, including diffraction, are interwoven and threaded together into the singular experience of one artwork which can contain several entangled themes, transmitting the ideas non-intellectually through visual, physical and experiential languages.

Exploring the property of diffraction using scientific diffractive materials created effects that enabled the expression of paradoxical quantum qualities such as indeterminism and the entangled nature of subject and object, giving them form and substance. The artworks demonstrate that, through diffraction, traversing the boundaries between dualities creates so much more than the sum of the parts; for example, the unification of light/dark, black/white produces a myriad of colours—substantially beyond the simple equation of black plus white equals grey.

Barad's applications are 'material-discursive' practices that are shared through their writing and lecturing. In contrast, some of the artworks for this enquiry are material-discursive-immersive activities resulting in physical artworks that provide visceral experiences and offer an alternative route to understanding through a visual and whole-body experience of seeing and perceiving the entanglements and quantum themes. (The discursive and immersive sections of the final exhibition, *Quantum Light—Beyond a Crisis of Perception,* are discussed in the conclusion.)

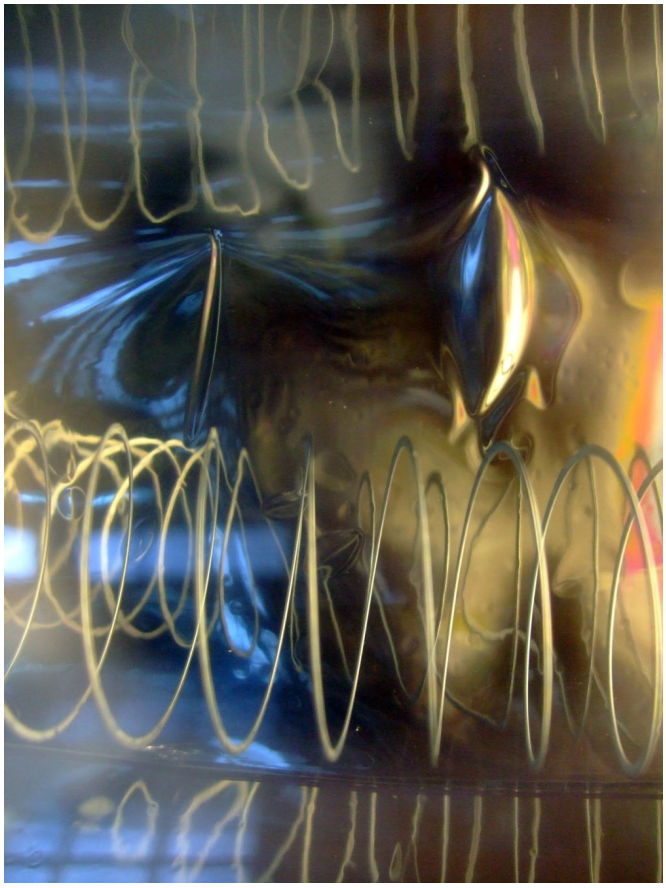


Image 93: Two-way mirror film, coiled spring. 2016.

Part III—The Science of Light: Unravelling Threads of Influence

Chapter 7
Unfolding from the Enfolded—David Bohm's Implicate Order

As discussed in the previous chapter, Barad's arguments extended from an alignment of Bohr's theories. However, on the other hand, David Bohm's theories of the implicate order were, in part, a departure from the Copenhagen interpretation and are discussed in this chapter. In *Science, Order and Creativity*, along with David Peat, he explained that the implicate order has been recorded in light waves summarising his theories thus:

> The actual order (the Implicate Order) itself has been recorded in the complex movement of electromagnetic fields, in the form of light waves. Such movement of light waves is present everywhere and in principle enfolds the entire universe of space and time in each region. This enfoldment and unfoldment takes place not only in the movement of the electromagnetic field but also in that of other fields (electronic, protonic, etc.). These fields obey quantum-mechanical laws, implying the properties of discontinuity and non-locality. The totality of the movement of enfoldment and unfoldment may go immensely beyond what has revealed itself to our observations. We call this totality by the name holomovement (Bohm & Peat 2000:180).

Bohm examined space, time, matter and light, considering matter to be condensed or "frozen light" (cited in Weber 1986:45), which is a powerful and useful characterisation. As with Moholy Nagy, Bohm, also experienced a light vision which his biographer, David Peat, described, "He dreamed of a light of such power that it would penetrate all matter—light so intense that its colour transcended blue and ultraviolet into some unknown colour beyond" (Peat 1997:12).

Bohm was concerned about the deeper causes of the nature of the subatomic world and was also interested in the philosophical implications of quantum physics. He strove to make the complex ideas accessible to non-scientists through many metaphors and analogies, most significantly the textile metaphor of folding to elucidate his theories of the implicate order. Understanding of his theories, metaphors and analogies are key to this research and motifs and ideas are woven through the artworks. His theories point to an fundamental order of unbroken wholeness underlying reality—the edge of becoming.

In the 2020 documentary *Infinite Potential: The Life and Ideas of David Bohm*, sculptor Antony Gormley explains how Bohm’s ideas inspired him. He states, "My interest in David Bohm is this notion that everything is becoming, everything is in a state of emergence."

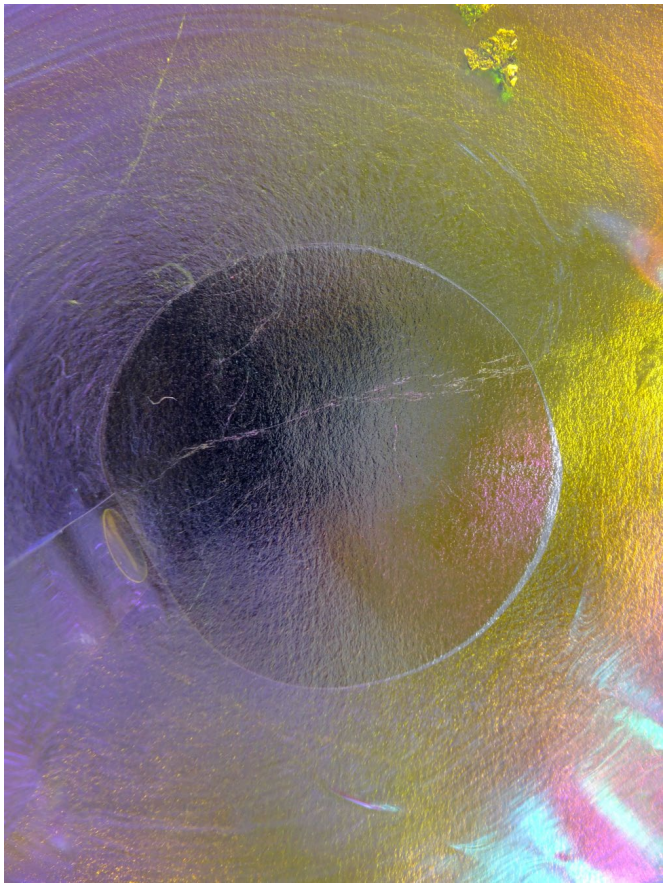


Image 94: Dichroic film, silver leaf on paper. 2018.

He goes on to explain how, in his understanding of reality, the surface of things is, in fact, the illusion (cited in Howard: 2020). Bohm's theories inspired the work of several other artists, including David Hockney.

David Bohm

Bohm was one of the most distinguished theoretical physicists of his generation (Hiley 1993:x) and his Causal Ontological interpretation offered a new approach to reconciling the contradicting viewpoints of relativity and quantum mechanics (2000:63-104; Bohm & Hiley 1993:13-54; Zajonc 1995:304-5; Sabbadini 2020:14). His theories challenged scientific orthodoxy; however, he never considered them to be complete, hoping instead that their insights would stimulate further research (Bohm 1987c:44). Although Bohm was marginalised by the establishment for various political and personal reasons, there has been a recent resurgence of interest in his life and theories including several symposiums and a recent documentary film *Infinite Potential: The Life and Ideas of David Bohm*. His theories have never been proved wrong by experimental physics; indeed, Arthur Zajonc observes that Bohm had a consistent theoretical account for every experiment that has been performed to date (1995:318). This includes the perplexities of the double-slit experiment (Pylkkänen 2010:164).

Bohm was interested in interconnected wholeness from the beginning of his career. Through his early research at Berkeley, he discovered *Bohm Diffusion,* a theory of plasmas (plasmas are high temperature gases containing a high density of electrons and positive ions that can be found in the sun but also exist in metals (Peat 2020:20)). His observations led him to wonder whether there was a deeper cause behind the apparently random nature of the subatomic world. He had observed that once electrons were in a plasma curiously they stopped behaving like individuals and started acting as if they were part of a larger, interconnected and organised whole—as if some process was coordinating their behaviour. In conjunction with discussions with Einstein and other physicists, he developed his theories of unknown factors or "hidden variables", which were followed later by his theories of the implicate/explicate orders, holomovement, quantum potential and active information.

Fragmentation

Bohm posed that the manifestation of all forms resulted from endless enfoldings and unfoldings. Unfolded explicate forms exhibit properties of separateness; however, they are ripples on the surface of the underlying and the deeper the implicate order (1980:48). Beyond the implicate order, he theorised further layers, the super-implicate, super-super

Image 95: Dichroic film, black beads, sunlight. 2021.

implicate and so on, each qualitatively different from, but mutually supporting, the others (Bohm & Peat 2000:180).

Bohm thought deeply about our perception of separateness (what he called fragmentation), devoting the first chapter in his seminal work, *Wholeness and the Implicate Order* (1980:1-26) to this topic. Bohm considered that separation and fragmentation encouraged a view of the divisions of things as being absolute and final. He felt that the common perception that reality is separate and fragmented resulted from thinking based on a mechanistic, atomistic worldview that gives primacy to externally related parts. He maintained that thought tends to create fixed structures in the mind that can make dynamic entities seem static (Keepin 1993:3) (this supports the aim of the artworks for this enquiry to question fixed positions). In his book, *Unfolding Meaning,* Bohm suggests a softer approach to reform the ego's identification of self as separate and its tendency towards fragmentation, by aiming to dissolve old patterns of thought and perception rather than contradicting, to controlling, or to destroying them by force (1985b:153).

Bohm posed that thought *about* reality creates a fragmentary view in which knowledge and reality are separate (Bohm 1980:18). However, he saw all reality, objects or things as dynamic processes rather than static forms (Keepin 1993:4). He saw fragmentation as "evidently and inherently destructive" (1985b:24) and at the root of many of the problems facing the modern world (1985b:24; Parry 2020:159). Bohm stated,

> To adopt such an attitude [of fragmentation] will evidently tend to prevent that free movement of the mind needed for clarity of perception, and so will contribute to a pervasive distortion and confusion, extending into every aspect of experience (1980:62).

To counter this, Bohm believed that thinking based on an understanding of wholeness would provide the potential for new solutions and approaches. Capra stated, "Ultimately—as quantum physics showed so impressively—there are no parts at all" (Capra & Luisi 2014:80), and Pylkkänen observes that with the theory of the implicate/ explicate orders, "A new part/whole relation becomes conceivable suggesting a new idea of the architecture of reality" (2010:57).

As previously, noted, the artworks introduce unexpected and unfamiliar sensory experiences that actively question the viewer's perceptions, acting on the RAS, offering a site for dissolving old patterns, thereby loosening fixed beliefs and positions, especially those based on a mechanistic and fragmented worldview.

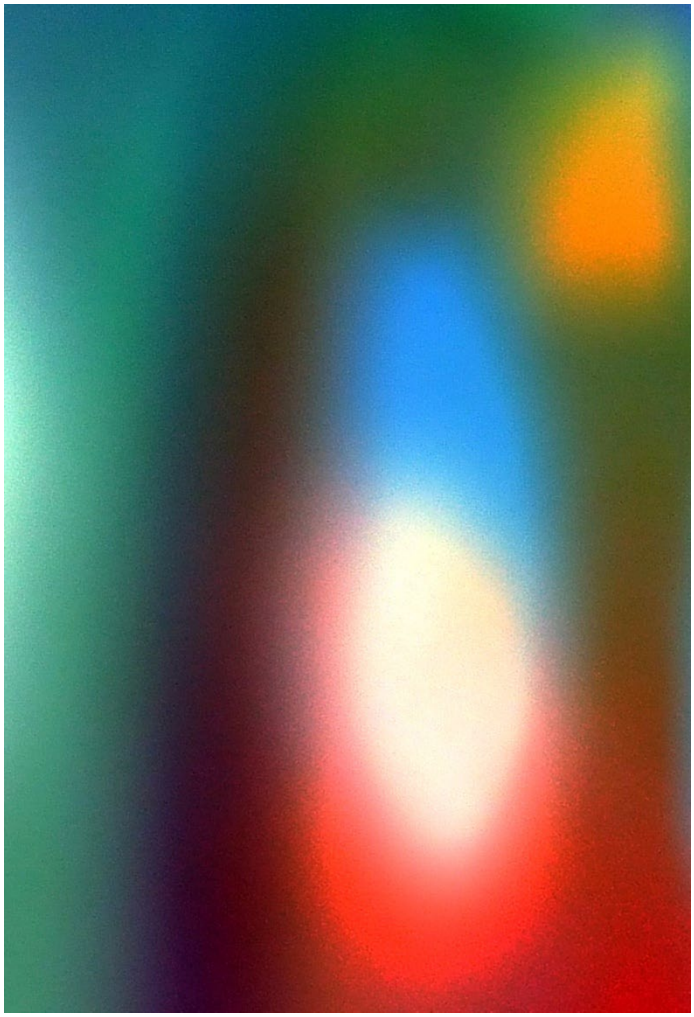


Image 96: Dichroic film, black ink drawing, sunlight. 2017.

Wholeness

Bohm believed that underlying, unbroken wholeness was fundamental to reality, saying, "Everything is woven together in indivisible links. The universe is one whole as it were and is in some sense unbroken" (1985b:7). Although the founders of quantum mechanics, such as Schrödinger, Dirac and Pauli understood wholeness (Peat 2020:26), Bohm recognised that an understanding of wholeness does not feature in many interpretations of his scientific contemporaries who relied on quantum mechanics as a system of calculation for experimental results and did not explore the metaphysical assumptions of their positions. Bohm observed, "I don't think the majority of physicists realise how radical the implications of quantum mechanics are"; notwithstanding, Bohm observed that wholeness is implicit in Einstein's relativity theory (1985b:7).

Einstein understood wholeness which he explained in a letter to a Dr Robert S. Marcus in February 1950, furthermore, he stated that our sense of separation is an optical delusion that should be countered by opening up to feel compassion for the whole of nature. He wrote,

> A human being is a part of the whole called by us 'universe', a part limited in time and space. He experiences himself, his thoughts and feeling as something separated from the rest, a kind of optical delusion of his consciousness. This delusion is a kind of prison for us, restricting us to our personal desires and to affection for a few persons nearest to us. Our task must be to free ourselves from this prison by widening our circle of compassion to embrace all living creatures and the whole of nature in its beauty (cited in Ricard and Xuan 2004:72).

Wholeness was equally well understood by the founders of quantum mechanics, including Danish physicist Niels Bohr, who had a fundamental understanding exemplified by his oft used phrase, "the inseparability of the observed and the observer" (Hiley & Peat 1987:10; Pylkkänen 2010:13). Although both Einstein and Bohr came from positions of wholeness, they had furiously debated the contradicting theories of relativity and quantum mechanics, leading to a split in the physics community. Bohm's encounters with Einstein changed the direction of his research, leading him to want to discover whether a deterministic extension to quantum theory could be found, thereby reconciling these opposing views (1987c: 38).

Physicist Shantena Sabbadini observes that for Bohm, reconciling relativity and quantum mechanics, did not require "a clever addition to a theory, or applying new mathematics, but rather proof that a radically new 'order' was required in physics" (2020:22). He adds that the "red thread" running through the heart of all of Bohm's work is the idea of order; he constantly returns to it, interpreting it and re-interpreting it in many ways (2020:14). The theory of the implicate order is founded on the question, "Is it possible to develop a new

Image 97: Photograph of red organza with pulled thread, 2015.

order that is suitable for thinking about the basic nature of the universe of unbroken wholeness?" (Bohm 1985b:8).

Analogies

Bohm developed his theories to answer why the multidimensional medium of space (the vacuum, plenum or void) can unfold the myriad forms that we sense and experience (1985b:8). Bohm went to great lengths to explain and describe the quantum nature of reality, not only to physicists but also to non-scientists. As these ideas are difficult to grasp, he used several analogies to help people visualise them. Two are particularly relevant here: the textile metaphor of folding and the hologram. Both lend imagery, depth and substance to the materials and motifs employed in creating the artworks for this research. Many of the artworks have titles that reflect Bohm's theories; moreover, the themes are expressed and embedded in their compositions and constructions of the works where they can be encountered both visually and experientially by others.

Bohm pointed out that these analogies only indicated a way towards understanding. He had been introduced to the work on semantics and meaning of Alfred Korzybski by artist Charles Biederman (Bohm 1987a) and, citing Korzybski's views' he explained that the analogies he used had their limitations. This is also true of the understandings embedded in the artworks (which use a visual language rather than a lexical language), however, they provide an experiential understanding beyond words.

Bohm used textile analogies of folding to describe the implicate, enfolded order (where everything is deeply interconnected and more fundamental) and the explicate (unfolded) order of reality. He posed that the implicate order is the essential order, whereas the Cartesian order (i.e. the order that science is most concerned with (Keepin 1993:6)) is the inessential order, being merely the appearance of what is going on in the underlying implicate order. He described thus,

> If you look at the mathematics of the quantum theory, it describes a movement of just this nature, a movement of waves that unfold and enfold throughout the whole of space. You could therefore say that everything is enfolded in this whole, or even in each part, and that it then unfolds. I call this an implicate order, the enfolded order, and this unfolds into an explicate order, in which everything is separated (cited in Wijers & Pijnappel 1990:29).

Hologram Analogy

The hologram was one of David Bohm's favourite analogies for explaining the implicate order (Bohm 1980:145; Bohm & Hiley 1993:353; Pylkkänen 2010:57-59) as he felt that,

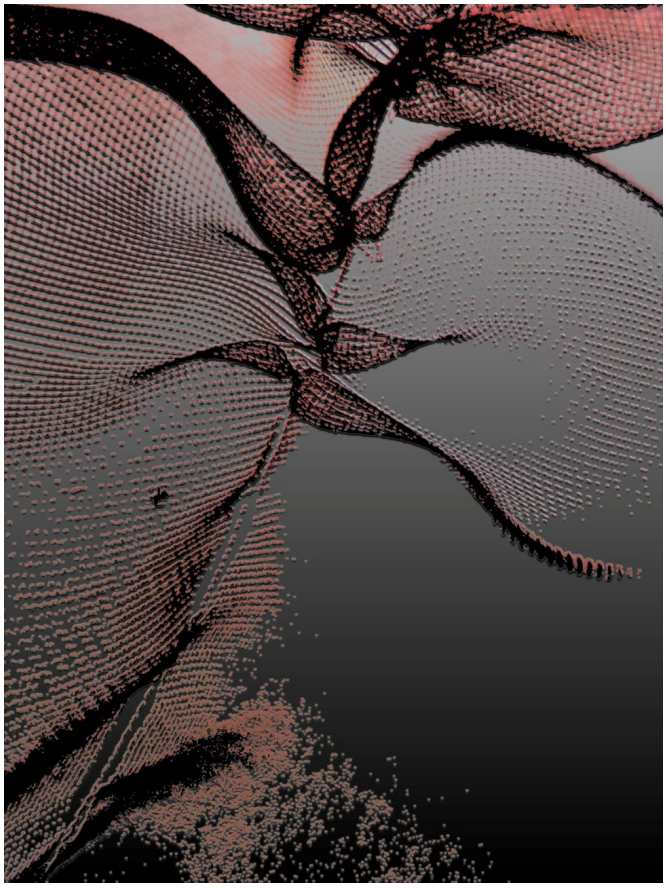


Image 98: Photograph of red organza with pulled thread, Photoshop filter and blend processes. 2015.

although it presented a static 'snapshot' of the dynamic implicate order (1980:177), it would help people to understand intuitively what underlies quantum mechanics (Bohm 1985b:31). He was primarily interested in the way that the information about the whole three-dimensional image is stored and enfolded in every part of the flat holographic plate—each and every region of the information on the plate contains an undivided image of the whole. Illuminating even a tiny fragment of a holographic plate with a laser will create a reproduction of the whole image (albeit less detailed). In the same way, Bohm believed that each part of reality contains information about the whole of reality, so that "a total order is contained, in some implicit sense, in each region of space and time" (Bohm 1980:149; 1997). Paavo Pylkkänen makes the point that enfoldment of information about the whole takes place in all wave phenomena (2010:19).

Holograms were invented in 1947 by Denis Gabor and the process was further developed with the invention of the laser in the early 1960s. A three-dimensional image of an object is created using coherent laser light and half-silvered mirror. The recording of the light field is made on a specialised light-sensitive plate. The half-silvered mirror splits the light into two identical beams that travel in different directions and the interference between them makes the three-dimensional image (Bohm 1980:145). Bohm noted that, because it records details using the wavelengths of light itself, a holographic plate has a very dense information storage capacity which is not visible to the naked eye. The pattern that is recorded on the plate is very complex and is composed of a series of moiré interference patterns (Bohm & Peat 2000:175). A hologram is an example of a non-local phenomenon because information concerning the whole is registered in every part. Therefore there is not a one-to-one (i.e. local) correspondence with each region (as in regular photography (Bohm 1985b:11). The point-to-point correspondence is associated with the more mechanistic scientific view (Pylkkänen 2010:58) as are reflections in a mirror or the image through a lens (Bohm 1985b:9) (see also Chapter 6 on Karen Barad's comparisons of reflection and diffraction, an interference behaviour).

Holomovement

Although the hologram analogy is an apt analogy for the implicate order, because the implicate order is a process of constant movement Bohm felt it was limited because a hologram is static (1980:177). Bohm devised the word holomovement (*holo* from the Greek for whole to incorporate ideas of movement, flow and flux (Bohm, 1980:150-157). The holomovement is "the unbroken wholeness of the totality of existence as an undivided flowing movement without borders" (Bohm 1980:172) and the "fundamental ground of all matter" (Bohm & Peat 2000: 180). However, Bohm advises that "the word 'holomovement' is merely a metaphor to point our mind in a certain direction and is not to be taken as

Image 99: ***Holomovement, #1.*** **Shoji paper, dichroic film, black ink, mirror, wooden frame. 1205mm x 940mm x 80mm. 2017.**

defined in any literal sense" (1997). Basil Hiley clarifies that Bohm's use of the idea of movement is subtle and profound—it is not simply the movement of objects, but instead, a more fundamental "primitive movement" from which space-time arises (2020:39).

Hiley grew up in India and was influenced by the thinking of Eastern traditions (2021c). He and his team are currently conducting experiments that he feels confident will prove Bohm's theories that quantum weirdness hides an orderly reality after all. He says of the experiments, "It is a new way of looking at quantum non-locality, which vindicates the Bohm position" (Ananthaswamy 2016).

Both wholeness and movement are important when considering Bohm's ideas of the holomovement and they are incorporated into the artworks. For example in *Holomovement #4* opposite*,* where, to suggest activity, the notion of the wave has become the swirl of a vortex, a moment of becoming within a dynamic void. In this work, the device of a vortex motif was used to meet the challenge of generating a sense of movement within a static artwork. The whirlpool motif refers to a dynamic enfolding/unfolding, paying homage to the notion of Bohm's holomovement. In his *Creative Credo* (1961), Paul Klee stated, "All becoming is based on movement…and likewise, in the universe, movement is the basis of everything" (1961:77-78).

Mirrors in the edge of the frame allow the work to extend outwards towards infinity beyond the boundary of the frame, suggesting a wholeness interconnecting with everything extending beyond. The form of the vortex is defined by changes in size and density in the mark-making and the image is hand-drawn in black ink. Although each is a separate dot, they are all part of the whole vortex: wholeness is suggested by repetition and symmetry which are design principles used to create unity (discussed in Chapter 8). A swirl of dichroic tubes follows the shape of the vortex and visually suggests transparent bubbles emerging from the void. Although the artwork is a static piece, a dynamic element is brought by the reflections of the dots in the glossy dichroic cylinders where the reflections take on changing colours and shifting forms as the viewer moves. The play of these coloured reflections invites the spectator to move physically as they notice that their movement influences and alters what they see.

Vortices

Bohm also used an analogy of vortices and eddies in the flow of a river to describe how regions of order could be contained within the continuous flux, stating, "Flow is in some sense prior to that of the 'things' that can be seen to form and dissolve in this flow" (Bohm 1980:11). In this analogy, even though a river is in constant movement, the turbulence

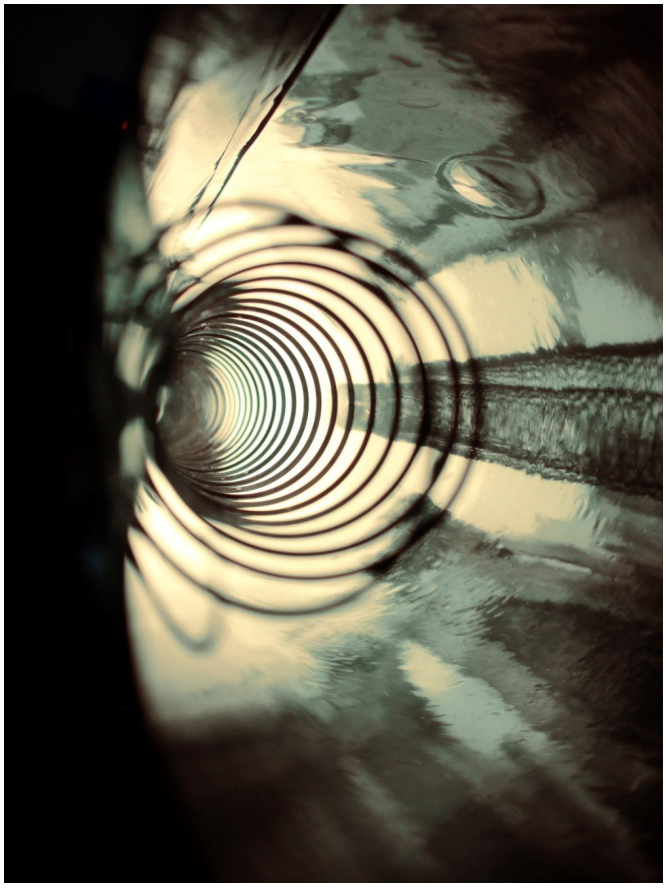


Image 100: Two-way mirror film, coiled spring. 2016.

patterns created by the vortices are relatively stable separate structures and manifestations of the explicate order. Nonetheless, they are one with the whole river and indicate underlying processes, the implicate order (Hussey 2020:172). Looking at three other approaches to vortices is useful here. Firstly, Leonardo da Vinci observed and analysed vortices; secondly, the philosopher Serres, who used fluid mechanics for thinking about a range of subjects, including physics, history and time (Clucas 2005), employed metaphors of vortices. Thirdly, artist Susan Derges recorded them with her camera-less art processes.

Almost six hundred years ago, Leonardo da Vinci was fascinated by these structures in flowing water; he closely and repeatedly studied wave patterns and whirlpools in rivers, lakes, waterfalls and laboratory tanks and recorded detailed observations of them, classifying different types and documenting them accurately in his drawings (Capra 2013:43-63). For Leonardo (as with Bohm), motion was of primary importance in thinking about the nature of reality. He identified motion as the primary power of four powers in nature, writing, "Speak first of motion, then of weight because it arises from motion; then of force, which arises from weight and motion; then of percussion, which arises from weight, motion and often from force" (Capra 2013:176).

Secondly, one of Serres's favourite motifs is the vortex, which turns on itself yet has a forward trajectory (Connor 2008). In *The Birth of Physics*, he examines vortices in relation to emergence, order and movement, and writes, "The origin of things and the beginning of order consists simply in the narrow space between *turbulence* and vortex…The first is simply disorder and the second a particular form in movement" (2000:28). With his characteristic poetic style, Serres draws on Lucretius's cosmology and considers the non-linear nature of flow and flux, conceiving that 'things of nature' are birthed in the multiple pockets of turbulence in the laminar (undisturbed) flow of the flux (Serres 1995:95-6). Stephen Clucas of Birkbeck University summarises Serres' view: "For Serres, the dynamic physics of turbulence and chaos, seen as a 'vortex of vortices' becomes the shifting foundation for a global theory of both man and nature" (2005:72).

Thirdly, waves are a key metaphor for Susan Derges in representing the interconnectivity and unity of all things, her inspiration coming from both Eastern philosophical thought and particle physics (Bucklow 2008). She is inspired by physicists, including Capra and Bohm, particularly Bohm's theories outlined in *Wholeness and the Implicate Order* (Ede 2005:173; Gaughan 2004). In making her photograms, such as the *River Taw* or *Shoreline* series, she immersed light-sensitive paper into rivers or seashore waters at night. A flash of light above the paper captured the peaks and troughs of the waveforms of

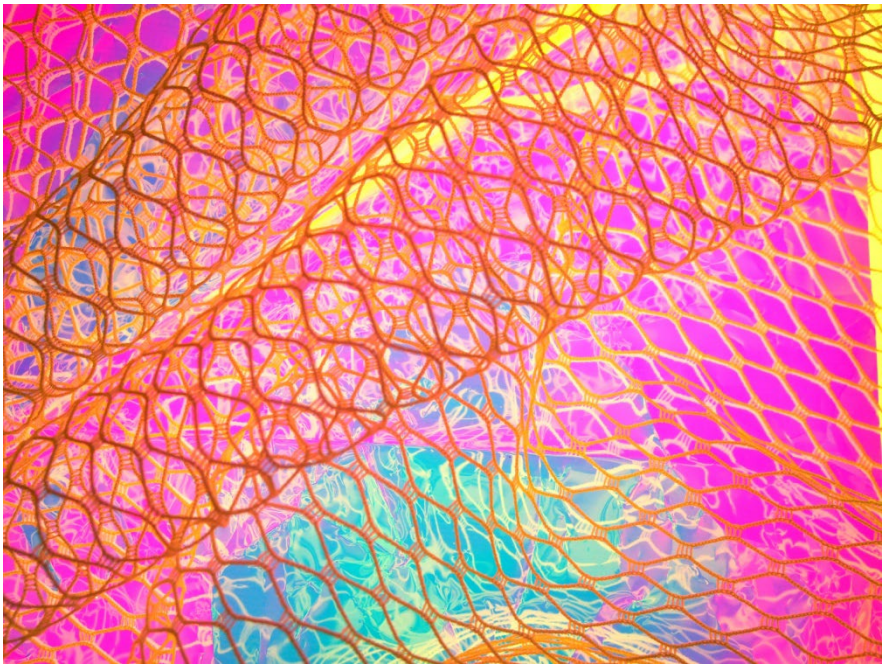


Image 101: Dichroic film, mesh fabric, LED light. 2019.

the vortices, turbulence and eddies in the flowing water. Writer Stephen Gaughan observes,

> She draws our attention to the whole which is isolated via the photogram, from its perpetual state of flux. It is a powerfully poetic and convincing demonstration of the interconnectedness of all things and also a wonderful illustration of David Bohm's 'Implicate Order' (2004:30).

Bohm's Reciprocal Relationship with Art

Bohm's interest in philosophy led him to dialogue with people from a wide variety of disciplines, including Jiddu Krishnamurti and the Dalai Lama who considers Bohm to be one of his "scientific gurus" (cited in Nichol 2003:x). For example, Bohm was in conversation with the Dalai Lama and artist Robert Rauschenberg and others in the session *From Fragmentation to Wholeness* at the conference *Art Meets Science & Spirituality in a Changing Economy* (1990). Beyond this, Bohm had a reciprocal relationship with art and artists, and he both influenced them and was influenced by them. In his essay, 'On the relationships of science and art' (1968), he described how, along with an 'embodied' cognition, he had discovered a new way of understanding that he gained by looking at art through talking and corresponding with artists (Howes 2005).

An intense ten-year correspondence exchanging ideas with the American structuralist and founder of Constructivism, Charles Biederman, was particularly significant to Bohm. It resulted in over 4,000 pages of letters and influenced Bohm's scientific thinking on wholeness (Bohm & Biederman 1999). Biederman, like Bohm, was concerned with generating new orders—Bohm was looking for new orders in physics and Biederman was looking for new orders in art (Peat 1997:233). Biederman had introduced Bohm to Cézanne and the Impressionists and Bohm saw parallels between the ways these artists applied paint and quantum theory which led him to a greater understanding of the relationship of the parts to the whole and the whole to parts (Peat 1997:233-235). David Peat, Bohm's biographer, suggested that Bohm's theories were in part inspired by Cézanne's approach to painting (1997:82-83). In a letter to Biederman on 6 June 1960, Bohm records that Cézanne's ideas on space as a unity of interpenetrating planes parallel the ideas he was trying to develop on geometry (Bohm & Biederman 1999:27). In the same letter, Bohm wrote,

> When you mention in your article in *Structure* that Cézanne saw the universe as a pulsation of colour, you remind me of some of my ideas on the wave-particle character of matter…Let us consider a pulsating model of the electron (cited in Pylkkänen 1999:32).

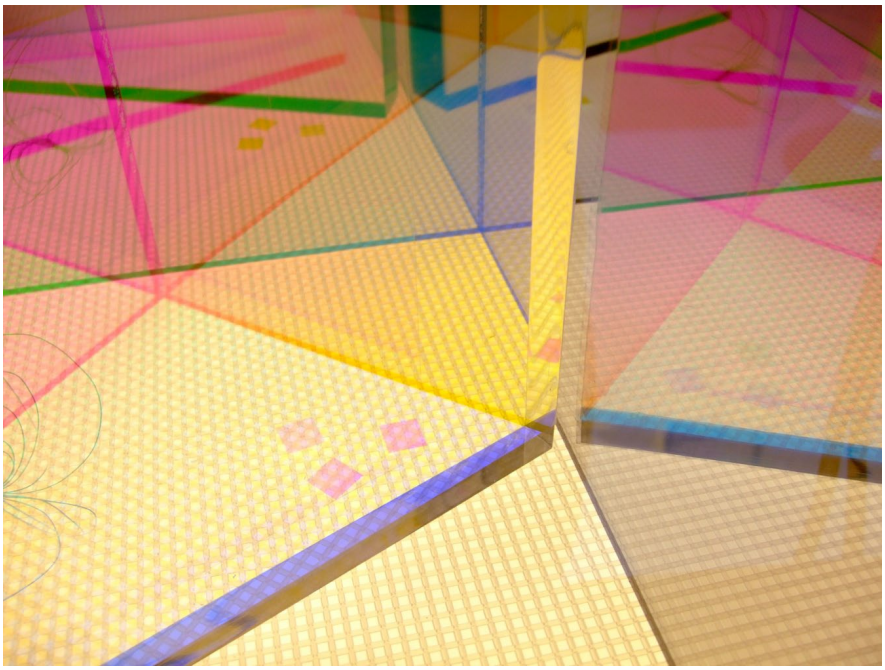


Image 102: Two-way mirror, prism, dichroic film, plastic grid fabric, wire. 2015.

Bohm acknowledged that the influence of art and artists significantly helped in his own scientific research as it enabled him to break free from the constraints of the usual scientific approach, leading him to, as he said, "look with a fresh view at structure as I perceived it directly with the senses...the mind is freed to consider new ideas of structure" (1968:173). In turn, Bohm felt that scientific ideas about structure could be equally meaningful to artists, writing in his paper, 'On the relationships of science and art',

> Not so much because they suggest particular ideas to be translated into artistic form, but rather, because if they are understood at a deep level they will change one's way of thinking about everything, including art (1968:173).

In turn, many artists have been directly inspired and influenced by Bohm's theories, including David Hockney, who translated Bohm's ideas into his own visual language after reading *Wholeness and the Implicate Order* (Peat 1997:264; McGill 1986).

Artists Inspired by Bohm

Liliane Lijn

Inspired by her encounters with Bohm at his seminars in 1974, Liliane Lijn was the only artist amongst the attending physicists. She became interested in his ideas and how he was trying to understand and imagine invisible phenomena and reality. In a *Tate Talk* in 2018, she recounted how Bohm compared reality to an interference system, as he explained that photons may create matter when they interfere with each other.

Since 1959, she has worked with light and the way it interacts with matter, bringing together science, technology, mythology, Eastern mysticism and poetry in her art. Transparency was an epiphany for her like Moholy-Nagy and Larry Bell (see Chapter 2). While waiting for a flight, she saw her reflection combine with the mountains, the airfield and the airport lights through the transparent/reflective medium of the plate-glass window. She describes the experience of blending of environment and self as truly formative: "I felt in that moment an intense experience of my own transparency and the ambiguity of solid matter, which has influenced all my work since that time" (cited in Brett 2002:70).

She works with the visual spectrum and "with the poetry of photons—and light in relation to matter" (2018). Exploration of materials is key to her work and she has pushed the limits of materials (plastics, metals, light and liquids) and processes "to the extreme limit of the material's own possibilities and the material therefore is in a state of constant tension" (cited in Brett 2002:69). She uses new materials, for example, Aerogel, which is used by NASA in its 'stardust' dust collector. Lijn says that Aerogel interacts with light in the same way the sky does (when light reflects off or passes through it, the colours change from

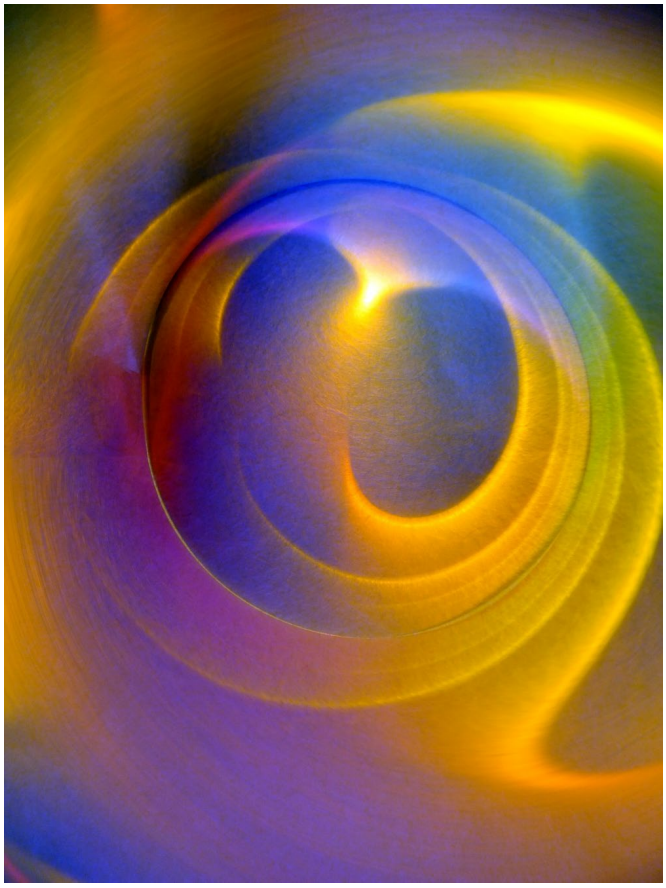


Image 103: Dichroic film, sunlight. 2017.

blue to amber) (See Fig 14). She recalled, "When I read his [Bohm's] words 'matter is frozen light', I thought of this material Aerogel because it does appear to be frozen light or frozen sky" (cited in Joelson 2019:110). Although a very different material to Aerogel, the dichroic film employed in this research changes the colours of light in a similar but more radiant way.

Figure 14.
Stardust Ruins: Ruins of Kasch.
2008.
©Liliane Lijn.

At this time, Lijn sought to uncover 'the roots of light' by exploring the way light interacts with matter (2018). Writer, Hilary Spurling, observed that "physics supplied her with the syntax and grammar of an evolving kinetic language" (2002:25). Her works of the 1960s and 1970s, such as her *Poemcones* (which later developed into her *Koans*) and her *Linear Light Columns* integrated science, technology, poetry and Eastern mysticism. She became aware that working with the invisible world of photons and energy vibrations took the emotional/spiritual out of the work: "I had discovered the poetry of light, water, movement. The purity of an energy unrelated to human emotions" (cited in Brett 2002:75).

Antony Gormley

As with other artists cited here, Gormley works at the intersection between art, science and Eastern thought (Miller 2014:163). He studied Buddhism in Sri Lanka and India (Miller 2014:163). Gormley explained that one aspect of Bohm's work that deeply affected him was "the participant nature of the observer in the emerging of what we call reality" (Howard: 2020). This is also true for the artworks in this enquiry; viewers activate the work and what they see is dependent on their viewpoint, perspectives due to changing viewing positions.

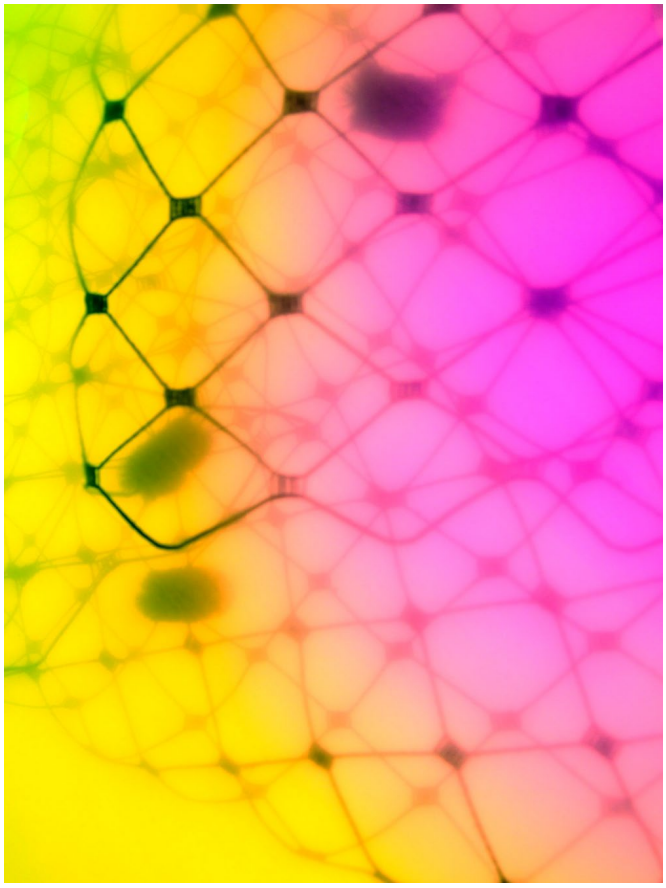


Image 104: Dichroic film, birdcage netting, LED light. 2016.

Figure 15.
Quantum Cloud.
Antony Gormley. 1999.
Photograph Andy Roberts.

In his thirty-metre-high sculpture near the Millennium Dome, *Quantum Cloud* (1999), made from interconnected steel sections, the more open density of branching connections describes the "bodyfield "space around a more densely composed human figure (See Fig. 15). He records that "it is an open question in the *Quantum Clouds*, whether the body is emerging from a chaotic energy field or the field from the body" (2009b). Gormley developed his ideas for this work following conversations about the quantum realm with physicist Basil Hiley, a close colleague and collaborator of David Bohm (Hiley 2017c; 2020; 2021a).

In *Another Singularity* (2008-2009), a multitude of chords connect a steel construction to points in the room; Gormley's description references Bohm's implicate order: "The work is an implicate order in which every trajectory has a dynamic and interdependent effect on the total matrix" (Gormley 2009a).

John Briggs

Artist, John Briggs, found correspondences between Bohm's theories of the holomovement and implicate/explicate orders and his own concept of 'reflectaphors' (1987:421). Having interviewed Bohm and discussed his ideas with him, Briggs was "surprised to discover someone in science who saw the world as an artist does" (1987:435). To Briggs, reflectaphors are an artwork's hidden order that emerges in the interactions of elements such as shape, lines, colour and negative space, "a kind of interference pattern" (1987:433). He states that "The reflectaphor is a hinge between the explicate order of our familiar reality (the grain of sand) and the implicate order (the whole implied by the sand)" (1987:434).

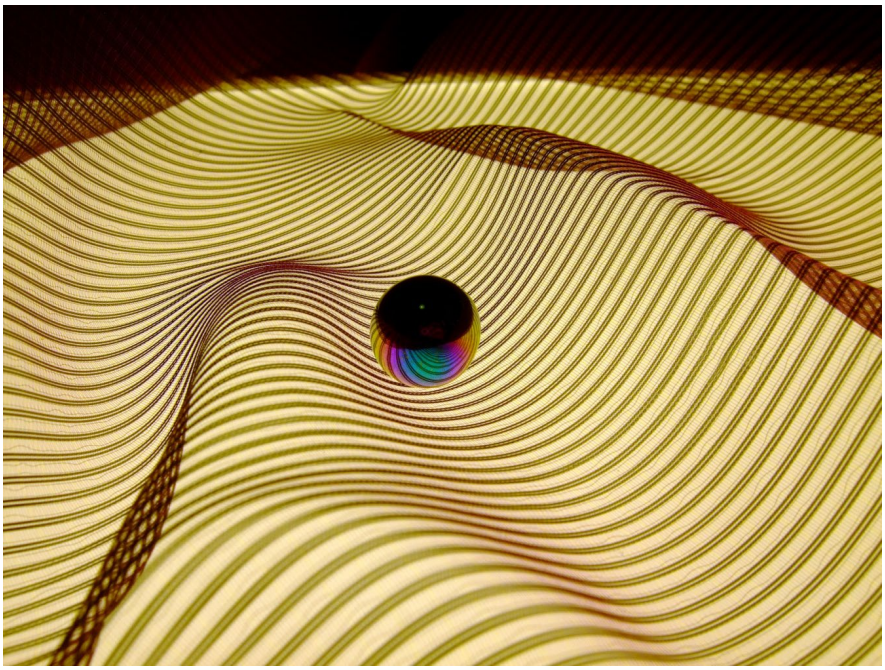


Image 105: Striped translucent cloth, tempered metal marble, LED light. 2016.

Bohm's legacy extends beyond his scientific theories and some artists have taken inspiration from these other aspects of his work. For example, Hester Reeve is inspired by Bohm's Dialogue work which she applies as a tool for creative discovery, social cohesion and cultural change, both within her art practice and the university sector. With an interest in the relationship between critical thinking and human agency in seeking solutions to world problems, she writes,

> Like Bohm, I am concerned to address the problems facing human society but realise that current solutions are made from the same mindset and understanding of reality that generated the problems in the first place and hence on the broader scale of meaningful existence are ultimately only adding to incoherence (2018).

*

Bohm recognised that his theories had broader implications beyond quantum physics. They are holistic and open up possibilities for new solutions based on different thinking, significantly pointing towards the potential for transformation. He presented them in ways that made them accessible to people from all walks of life and some of the metaphors he used have inspired themes and motifs in this research. His willingness to be influenced by other disciplines and his openness to learn from them enabled him to further his thinking and develop his theories. This inclusive approach has served as a useful model and is truly inspiring. For example, by theorising a new order through which to view reality, rather than taking an either/or position, he sought creative leaps to look beyond and reconcile the contradictions between relativity and quantum mechanics. In response, this research actively embraces many viewpoints, entwining and entangling them through textile thinking so that they can congruently exist together in the same space. In addition to the textile thinking, art practice is an ideal syncretic methodology as it also permits an interweaving of ideas, themes and materials.

Bohm's metaphors have been woven into the creation of the artworks, the foremost being folding, enfolding and unfolding, which thread throughout the research and link to the textile methodology engaged. Folding is used both as a motif and a process where actions of folding were applied in various ways to fold and pleat both cloth and other unlikely materials, such as mirrors in the *Unfolding Light and Space* series creating origami-like reflections to open the contained space of the vitrine towards infinity. The themes inspired by Bohm's theories incorporated into the artworks include implicate/explicate orders, enfolding/unfolding, wholeness, vortices, particle/wave duality, the observer effect and the holomovement. The way these themes inhabit the work is more fully described in Part IV.

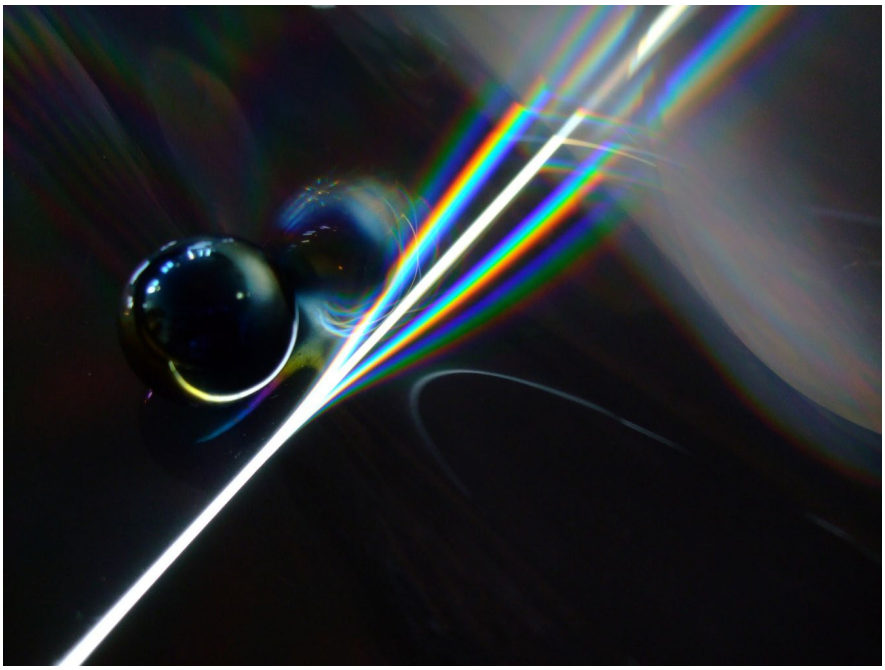


Image 106: Black paper cut with one slit, black marble, diffraction grating, LED light. 2021.

Part IV—Making Material

Overview

Art helps us to see in new ways, expanding on other systems of knowledge. Although arts-based research may be non-discursive, its expressive, aesthetic properties are affective and are therefore a valuable way of understanding (Barone and Eisner 2012:171). In analysing arts-based research, Graeme Sullivan draws parallels between scientists and artist-researchers. The process of this research draws from both art and science through a series of systematic enquiries into the nature of the materials used. As Sullivan observes,

> Scientists and artists who are really interested in finding order within chaos and who see the microworld and macroworld around us as the lab or the studio are looking deep into material processes and organizing patterns with surprising outcomes. And these investigations often get carried out in the spaces between disciplines and without the safety net of codified practices (2010:119).

Both the materials used and the active making processes are central to seeking visual solutions to understanding scientific enigmas and philosophical questions. The relationship between the material investigations and the resolved artworks is entangled, so, for clarity's sake, the discussion of aspects of the artistic practice is presented in three chapters in Part IV that cover the materials, art process and outcomes.

Firstly, in *Chapter 8—Material Investigations* there is a discussion of the optical materials explored through 'material investigations'. These are a quasi-scientific process of repeated experiments to uncover the properties and possibilities of various materials and they function in three ways: firstly, as a process of exploration towards becoming conversant with the material; secondly, as a way of thinking through materials to allow experientially based comprehensions to contribute to other cognitive processes and thirdly, as a route to developing new ways of expressing the themes that arise from the theoretical aspects of the research. Properties of these physical materials both illuminate and reinforce understanding of the nature of light and enable expression and communication of the philosophical areas of concern which are multifaceted and difficult to articulate with words.

Observations of two materials, prisms and diffraction grating, are discussed in more detail to demonstrate the process. Prisms demonstrate the classical nature of light whereas diffraction grating expresses quantum properties. As Barad observes, "Diffraction plays a crucial role in sorting out some key issues in quantum physics" they remind us that "perhaps one of the most well-known dilemmas in quantum physics is the 'wave-particle duality paradox'" and continue, "What lies at the heart of the paradox is the very nature of

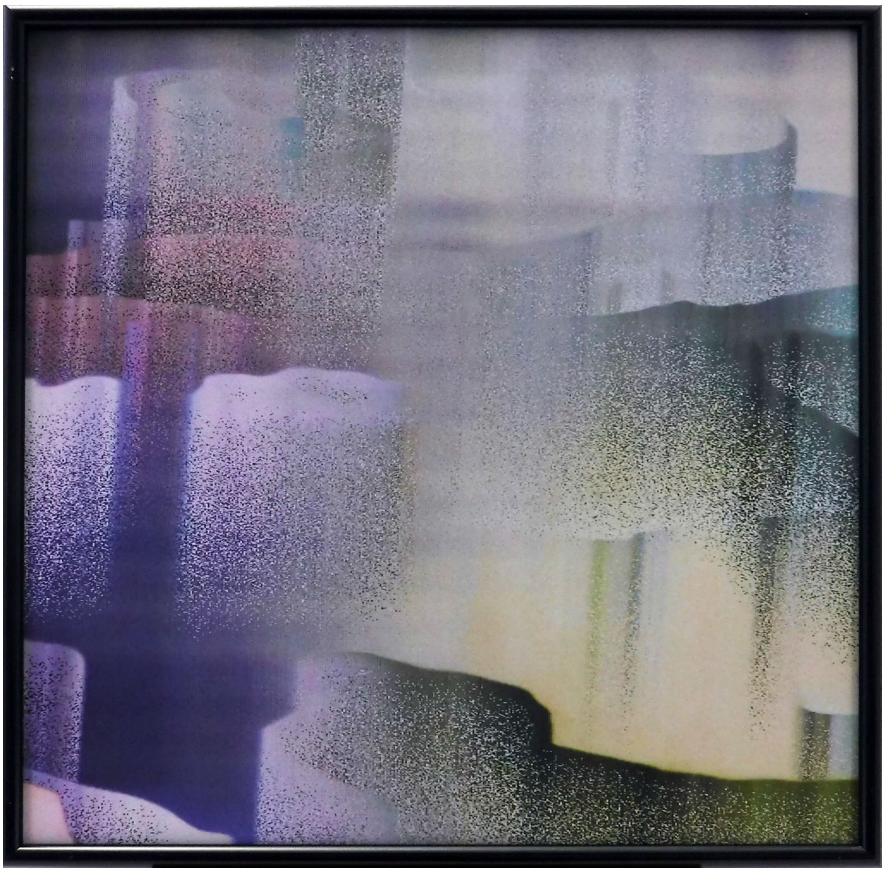


Image 107: Lenticular photograph created from film still positive and negative images, frame. 300mm x 300mm. 2019.

nature...diffraction phenomena play a key role all along in helping to illuminate the nature of nature" (2007:29).

Secondly, in *Chapter 9: Process—Lenticular Series,* the developments of the several Lenticular series are treated as a case study to demonstrate the evolution of the artistic process (which is also complex and entangled). There is a detailed account of how the evolution of these factors intertwines with the themes that emerged into and through the research. The physical and optical qualities of lenticular photography are explored, followed by an explanation of how the limitations of lenticular production were developed and subsequently pushed beyond the usual limits of their production. This generated novel outcomes that contributed to illumination of the themes, in particular, Bohm's holomovement.

The last chapter in Part IV is *Chapter 10: Resolved Outcomes.* As it is not possible to discuss all the thirty-plus series created during this project four resolved artworks were selected for analysis in this section. Reflection on these works resulted in unpicking and examining the synergistic elements within them, which included, artistic devices and processes used, the artistic use of optical materials and how they express and interrogate some or all of the theoretical and philosophical themes arising from the study of light that thread throughout the research. These include highlighting the underlying oneness and interconnectedness of all things, representing the paradox of unity from multiplicity, the edges of becoming and presenting unified dualities while expressing and revealing the hidden, immaterial aspects of our reality. This chapter concludes with a description of the final exhibition, *Quantum Light—Beyond a Crisis of Perception,* which includes these and other resolved artworks and immersive installations.

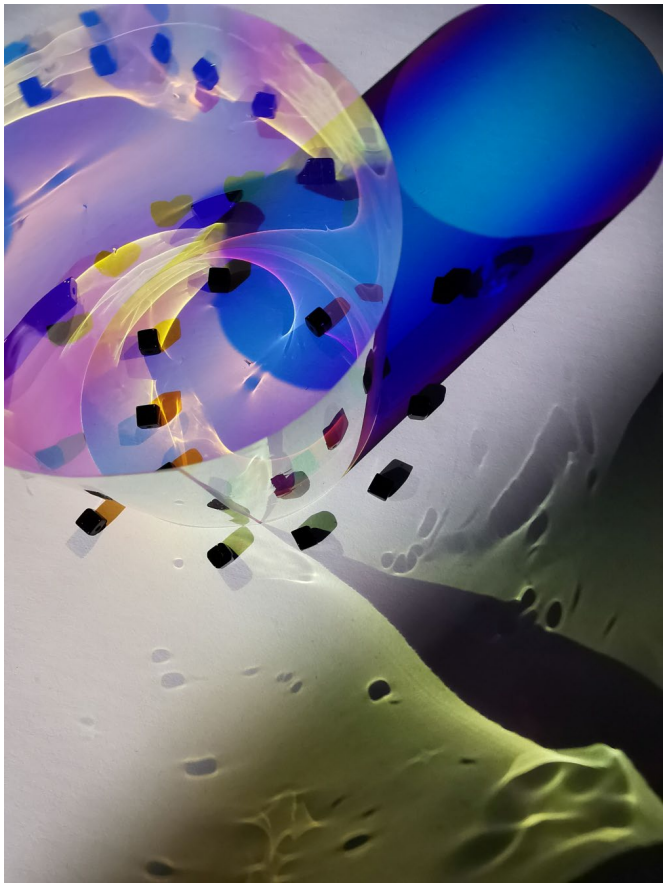


Image 108: Dichroic film, black beads, sunlight. 2021.

Part IV—Making Material

Chapter 8
Material Investigations

In this chapter discussion of the value and process of thinking through materials is followed by an examination of specific materials which are used in the two-slit experiment (see Chapter 5). The meanings of the word material also includes both cloth and matter, linking the subject of this research (materiality/immateriality) with textile thinking. An in-depth exploration of two materials—prisms and diffraction precedes a brief account of the exploration of half-silvered mirror and dichroic film (which are beam-splitters used in two-slit experiments). These materials are appropriate in expressing both the classical and quantum properties of light.

Through the course of this enquiry into the nature of light it became apparent that optical materials commonly found in physics labs used as beam-splitters could, by their nature and physical properties, interrogate the areas of philosophical enquiry that emerged from the scientific examination of light. In the two-slit experiment, beam-splitters such as prisms, diffraction grating, dichroic materials, mirrors or half-silvered mirrors replace the slit openings and channel the path of light in more than one direction. These materials were already being used intuitively in the early stages of this research before the significance for their two-slit experiment was appreciated—the fact that they are used in double-slit experiments makes their application in this enquiry all the more relevant.

Half-silvered mirror is used as a beam-splitter and is characterised by its capacity to both reflect and transmit light. This is true, to a lesser degree, for all glass, and scientists (going back to Newton) are aware that it is not possible to predict whether a photon will be reflected or pass through the glass; science writer Brian Clegg explains that this is due to the quantum nature of photons (2014:78). It is worth remembering Larry Bell's observations here that glass and half-silvered surfaces in his artworks do three things simultaneously: they transmit light, they reflect light and thirdly, they also absorb it to some degree (see Chapter 2). The use of half-silvered mirror in artworks for this enquiry is discussed in more detail in Chapter 10.

Thinking through Materials

As discussed in Chapter 4, Irwin and Springgay characterise the artistic process through the cognitive functions of theoria, praxis and poiesis (looking, thinking and doing)

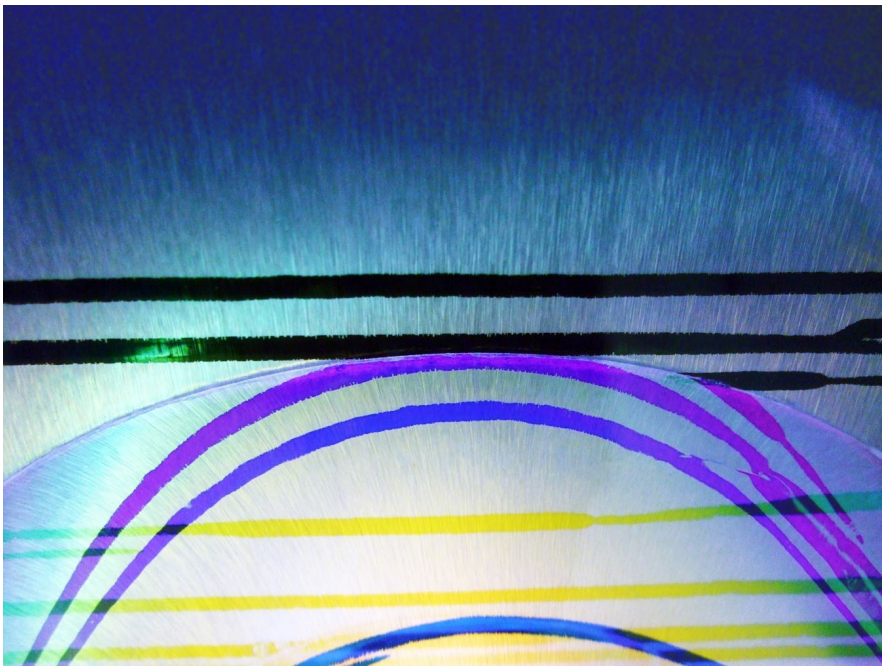


Image 109: Black ink drawing on brushed aluminium substrate, dichroic film. 2016.

(2008:107). These are fundamental to the examination and application of the materials used in this enquiry, and the artistic process of seeking both the unusual and aesthetically pleasing engages looking—theoria (theoria means contemplation, speculation and looking at). Looking requires focusing attention, close observation and noticing and it oversees the doing and making. The doing informs the subsequent evolution and re-working of ideas and motifs. Thinking is engaged in both the exploration of the materials used and the active making processes that are central to seeking visual solutions to understanding the scientific enigmas and philosophical questions. Moreover, it both precedes and follows the actions of doing and making as well, through invention, decision-making and analysis of and reflection on the outcomes.

The resulting material investigations are central to this enquiry and are interwoven processes of all three. They contribute to the knowledge gained through innovative approaches that generate novel forms, offering unique experiences of the materials. Theory implicitly underlies these investigations, both consciously and subconsciously colouring the directions they take.

A photographic dataset was gathered to record the outcomes of the material investigations providing a non-verbal contribution to knowledge. Although photographs cannot fully convey the phenomenological experience of the investigations they serve to evidence the practice. Moreover, they aggregate to create an overarching oeuvre that holds and represents the themes identified in this research. Many of these images accompany the text of this thesis as a photo essay—a non-linear form of information that visually supports and extends the linear text. Together the photographs and the text offer a dual and more complete whole brain experience of the interwoven subject matters.

Sampling

Doing enlists 'sampling', a hands-on experimental process of design development (fundamental to textile design) that is key to becoming conversant with materials. In this research, sampling evolves and refines the information gained through repeatedly applying endless variations and adjustments to the compositions of the set-ups of the materials: observing and responding to those variations develops the visual outcomes. The direction of this experimental process is not attached to success or failure but is guided by aesthetic sensibility and a feeling and recognition of what 'works'. Each discovery led to further adjustments, exploration and analysis which revealed both peculiarities of the materials in question and aspects of the nature of light itself, opening into new avenues of enquiry.

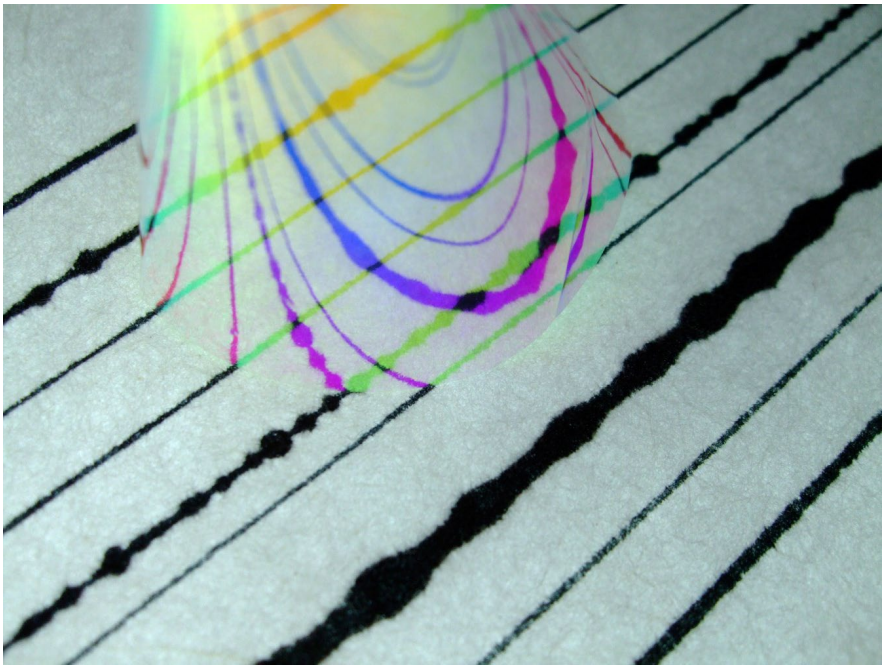


Image 110: Black ink drawing, dichroic film, LED light. 2017.

Sampling is an essential element of textile training and is fundamental to textile design and the sampling of (often hard) materials other than traditional soft textile materials is approached in the same way in this research. The sampling process developed an understanding of the materials' behaviours, surfaces, textures, opacity and optical qualities. It explored their potential to question our perception of reality and generate surprising visual outcomes which reflect the paradoxical themes, such as expressing and revealing the hidden, immaterial aspects of both light and matter.

Conscious and Unconscious Processes

Looking and doing are closely related activities and are interwoven with theory through thinking which is both conscious and subconscious. Conscious thinking deliberately serves to find the links between the philosophical themes (such as Bohm's enfolding/unfolding implicate/explicate orders) and the material qualities observed through looking and doing. Doing entails following an intuitive sense to allow a flow from the unconscious to percolate into the work so that a synthesis of ideas and other elements spontaneously and immediately emerge into it without conscious control or direction. For example, the initial choice of materials (prisms, half-silvered mirror and dichroic materials) was intuitive. Their relevance to the two-slit experiment and the quantum questions it reveals only emerged later as the research into the properties of light progressed and became centred on these experiments.

Thinking-through-making in this way is a speculative process and is an interface with the unknown that allows for innovation. Outcomes are not wholly controlled, allowing for chance, synchronicity and coincidence to create new, unexpected forms and processes to reveal, hitherto, hidden patterns, connections or themes. Sullivan concurs,

> Artists have within their imaginative intelligence the capacity to create new opportunities for us to see, feel, and know things that can change us. Yet these insights, like all forms of understanding that emerge from thought-provoking enquiry, are a result of a fluid interplay of planning and surprise, perspective and uncertainty, theory and practice. The messy resistance of human knowing relies on the rationality of intuition as much as it does on the creativity of the intellect (2010:xvii).

Through an engagement with the materials, the subconscious and intuitive creative processes allow for the interconnected but seemingly unrelated themes (such as unifying dualities, interconnected wholeness, transparency, the entanglement of observer and observed and questioning of perspective and viewpoint) to be entwined and unfolded and coherently reside in the same space of an artwork. The art thereby become a source of fresh thinking and make these qualities accessible to others through a visual language

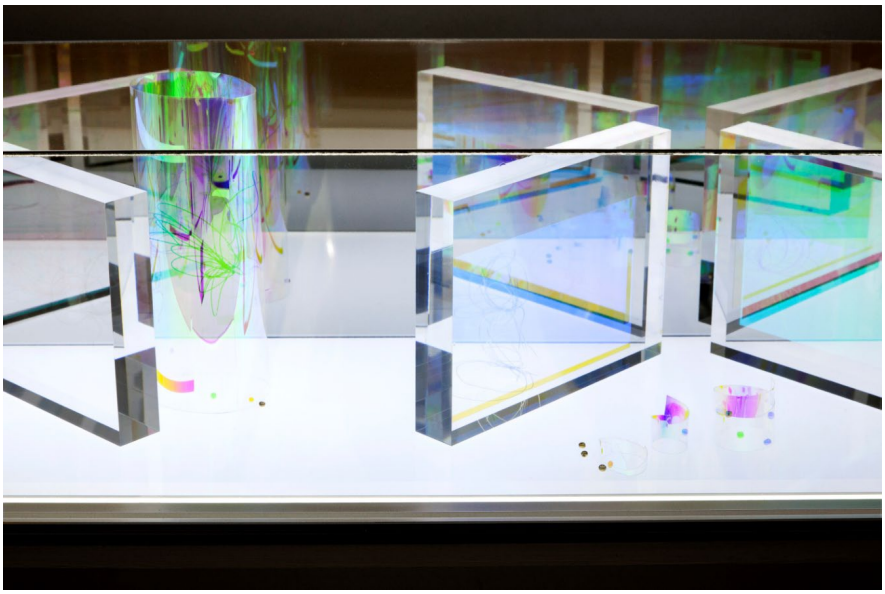


Image 111: *Unfolding Light and Space* #1. *D*etail view. Prisms, two-way mirror, wire, gold beads, LED panel. 250mm x 300mm x 1200mm. Photograph Ibolya Ferher. 2015.

that directly affects perception and offers the potential for viewers to shift beliefs, such as dualistic either/or to both/and positions.

Light and Surface—Prisms

Arthur Zajonc, a physicist specialising in quantum optics, explains that light is in fact invisible and we only know of its presence through the way it touches matter (1995:2). By illuminating surfaces and objects in its path, light reveals properties of reflection, refraction and diffraction and the practical investigations are, in effect, set-ups for materialising the properties of light itself to observe its relationship with the surfaces of various materials. Through the processes of looking, doing and making, several general questions were asked of each material, including,

> What are its qualities or properties?
> What does it look like? What does it do?
> Can this material be used differently from how it is commonly used?
> How does it combine with itself or other materials? Does this change what it does or says?

Further individual questions arose that were specific to each material. For example, the following questions were asked of prisms:

> What is happening on the surface, what is happening internally and in the surrounding space?
> How does the shape of the prism affect what is happening?
> What happens if two or more prisms are adjacent to each other?

The resulting observations revealed a variety of optical properties that helped illuminate the nature of light, which then led to many further questions, such as,

> What is the nature of transparency?
> What is hidden? What is revealed?
> How does this alter perspective?

Since Newton, prisms have been used for splitting light into the seven wavelengths of the visible spectrum. However, this particular property of prisms is not explored here; rather, the focus is on their transparency and how they simultaneously refract, reflect, transmit and absorb light. Unravelling the spectrum is explored through using another material, diffraction grating (see below).

Some material investigations focused on how the internal reflections in a cuboid prism interrupt the regularity of a lined background surface, visually disturbing the flow of the regular pattern. Sampling with differently shaped prisms revealed other optical effects, for

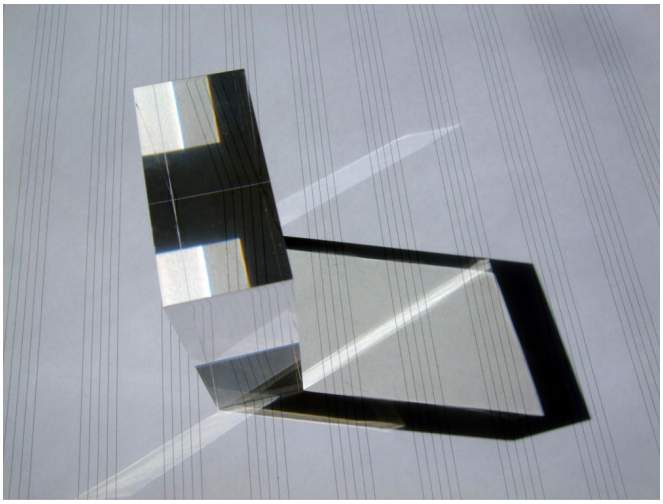


Image 112: Music paper, prism, sunlight. 2015.

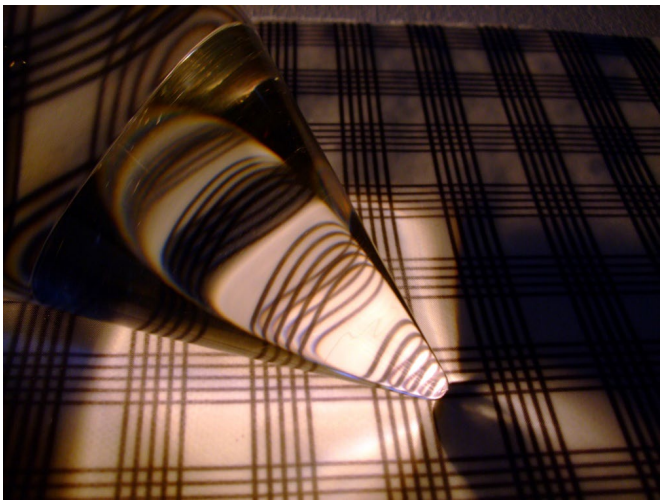


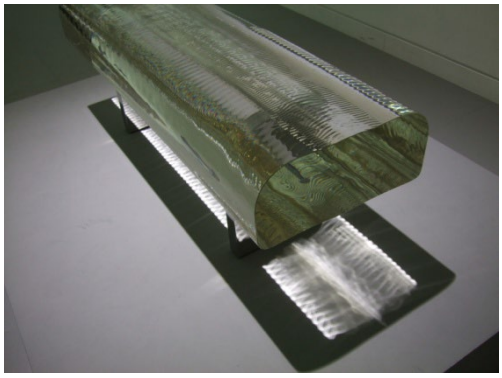
Image 113. Printed fabric, cone-shaped prism, lamp light. 2015.

example, with triangular prisms, the interrupted pattern becomes more intricate and complex. The reflections in cone-shaped prisms are even more complex, the orderly straight lines of the background grid pattern become sinuous in looped folds as they coil from the two dimensions of the background surface to three-dimensions within the cone (see Image 113). These particular properties of cones were used in the mini *Beyond Duality* series (see Chapter 9).

Prisms—Internal Reflections

Artworks by Tokujin Yoshioka, seen in an exhibition at the Mori Museum in Tokyo, inspired the use of prisms in this research.

Figure 16.
Water Block. 2002.
Tokujin Yoshioka.
Photograph Peta Jacobs, 2010.



The way that *Water Block*, 2002, was illuminated for the exhibition revealed a complicated 'shadow' that is both dark (as shadows typically are) but also had areas that were much brighter than the surrounding floor (See Fig. 16). These two features were also observed in the material investigations of prisms (See Image 112 opposite). The particle nature of light means that it propagates in straight lines and internally reflects, collects and intensifies when travelling into and through the prismatic form. Firstly, as a prism is transparent and there are no opaque surfaces to a prism, a question arises: 'Why are dark shadows cast?' A prism is transparent and we expect to see straight through it—deep shadows would typically indicate complete opacity, questioning what we perceptually 'know'. It appears (paradoxically) as if the sides of the prism have become opaque and no light travels through them even though they are transparent and one can see straight through them. The dark shadow indicates the degree to which the light has been reflected off the internal surface within the prism. Not much light passes through. Secondly, the light reflected out of the prism casts brighter areas into the surroundings, as it might if there was a light source *within* the prism. The prism acts as a lens, focusing and intensifying areas of light.

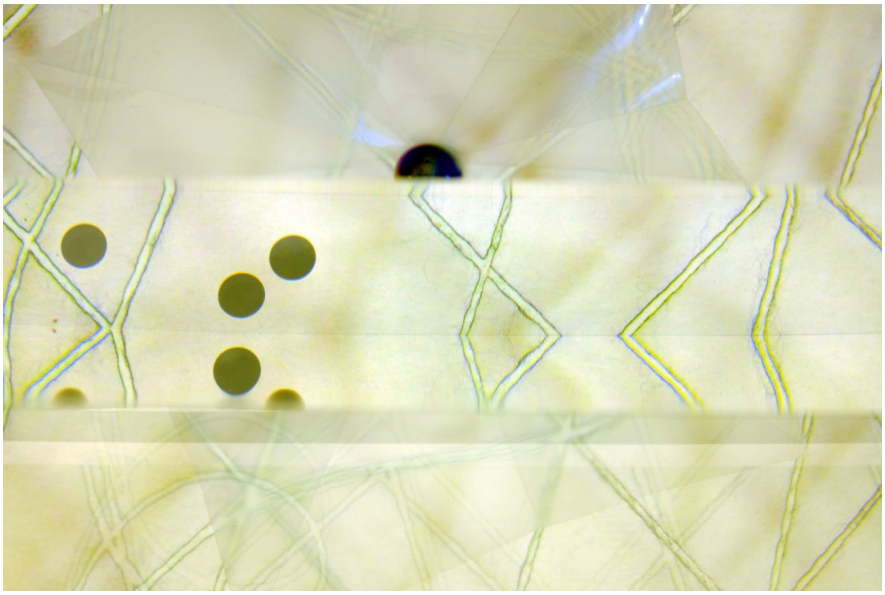


Image 114: Printed paper, prism, three gold dots, black marble. 2015.

Hidden in Plain Sight

Close observation reveals several visible 'surfaces' of a prism—one sees both the internal reflections and right through it to the other side simultaneously. What someone sees depends on the angle of viewing of a particular surface: square on, one sees straight through; obliquely, one sees the internal reflection. Hence, it is possible to see both the internal and external surfaces of a prism simultaneously, offering an experience of simultaneous dualities. Moreover, one can shift one's focus of attention from one to the other in a perceptual dance—presenting the inclusive position of both/and, not the binary of either/or (Ascott 2005).

These observations led to the discovery that, due to the internal reflections, elements within the prism-sampling set-ups were only visible from certain viewpoints and were concealed from other views. These elements become hidden in plain sight, a feature that is employed in several artworks such as the *Unfolding Light and Space* series. In the material investigation on the opposite page, a black marble lies beside a prism that sits on a background printed with straight green lines. Several small gold dots lie underneath, between the prism and the background (See Image 114). These particles can only be seen through the top surface of the prism and completely disappear from view when the set-up is viewed from any other angle. Moreover, when seen from directly above, the dots become multiplied—even though there are only three original gold dots under the prisms, we see companion dots. These reflections are merely an illusion and our perception of reality is questioned as it is hard to distinguish between real and virtual—things are both there and not there. Even though different views present different experiences, all views are equally 'true', so a fixed or partial viewpoint is questioned. The set-up becomes an 'apparatus' that points to a hidden order that exists beyond all things—things are not always what they seem. Looking into the prism, the straight lines on the background surface become folded upwards to form angular 'waves' that only appear at certain viewing angles; their orientation changes as the viewer shifts position. Together with the gold 'particles', they create an uncertain and shifting wave/particle duality.

Material Investigations—Diffraction/Interference

Initially, the sense of whether diffraction grating could convey pertinent meaning was purely intuitive and it was chosen for its almost magical abilities to disperse white light into its spectrum dynamically and playfully. As the theoretical and scientific study progressed, it became clear that these surprising optical effects make it a material ideally suited to developing the exploring the perplexing quantum-based themes of this study.

Image 115: Diffraction grating, black ink drawing on white paper.

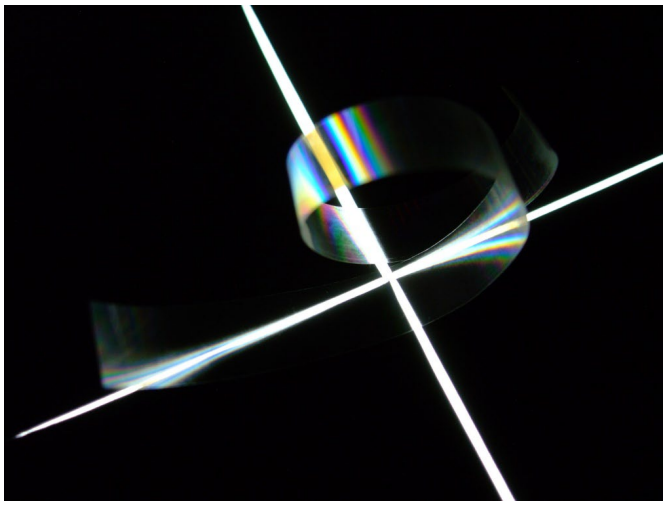


Image 116: Diffraction grating, black paper cut with two slits, LED light. 2015.

Adjusting Set-Ups

Slight alterations in a set-up can lead to dramatic visual changes. For example, sampling with just three elements (diffraction grating, an LED panel for backlighting and cut paper) produced the two different effects in the images opposite, revealing the spectrum colours hidden in white light in different ways. The first is a sample from the *Cutting-Together-Apart* series (see Chapter 6 for Barad on this). Diffraction grating was threaded through slits in the thin white paper, the dark lines seen through the diffraction grating are diffracted and distorted to produce a series of soft, subtle, rainbow-hued penumbras that echo the forms of the lines.

In the second sample, the white paper was replaced with black paper cut with narrow slits which allowed thin shafts of light to shine through diffraction grating which resulted in bursts of intense rainbow colours emanating from the white light. These fountains of colour are nothing more than an optical effect unravelling the spectrum from white light. These vivid colours are more akin to those produced by the use of diffraction grating in a scientific setting for spectrometry in a darkened space (where beams of light are directed through a chemical sample to measure it. The light is dispersed by the diffraction grating to create bar-shaped patterns of coloured light, the pattern of colours determining the composition of the materials of the sample.

In viewing these set-ups a question arises: "What is actually real here—the monochrome materials of paper, ink, diffraction grating and white light or the dance of colour, or both?" This challenges perceptions and a fixed viewpoint and offers clues to the hidden dimensions that exist beyond the world we experience. By making the wave nature of light explicit, diffraction creates effects that are more than the sum of its parts.

Disrupted Boundaries and Superposition

In addition to providing experiences of the truly colourful composition of white light, diffraction grating also makes questions of boundary explicit. The first photograph on the next page (See Image 117) provides a clear example of one of the most noticeable optical features of diffraction grating, which is the disruption of the boundaries and edges of things seen through it which are created by its wave interference properties. The colours, the shapes and the sizes of the overlapping diffracted squares are not fixed and are altered by shifting the viewing distance.

In the set-up overleaf (Image 118) entangled, dynamic, complex, multi-hued patterns were formed by a chequerboard grid of nothing more than alternating black and white squares layered with diffraction grating. It provides experiences and sensations of simultaneity of

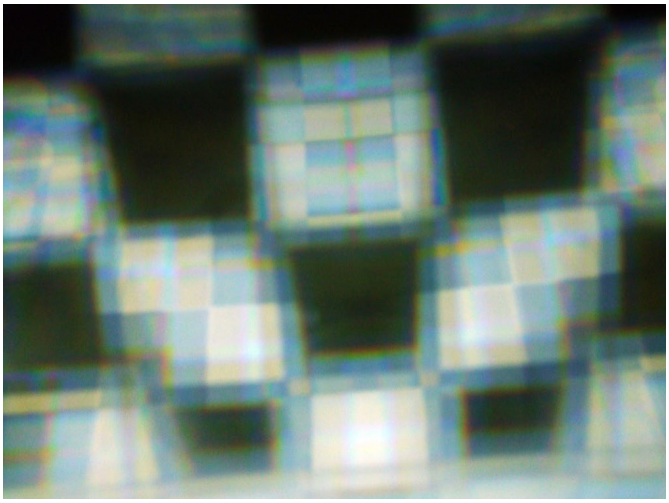


Image 117: Black and white chequer-board print, diffraction grating. 2018.

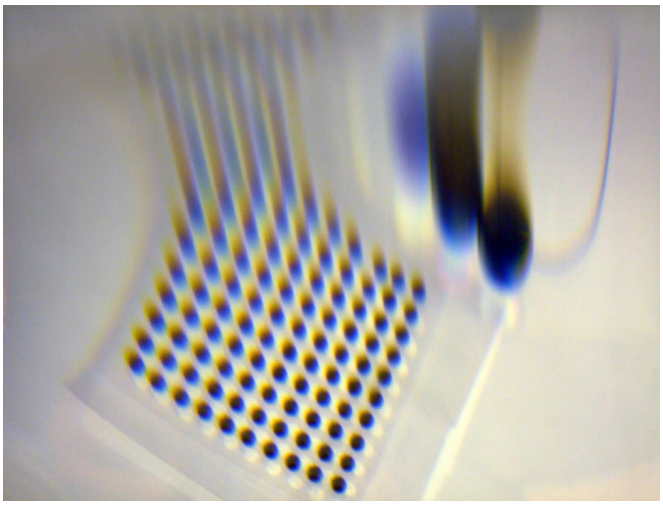


Image 118: Diffraction grating, rhinestones, one black marble, LED light. 2015.

quantum dichotomies and interference superpositions. Quantum superposition is where a single particle is apparently either in two places or has a mixture of states simultaneously. This effect is also described the resolved Artwork 3: *Unfoldings—Implicate/Explicate I* section in Chapter 10.

Barad reminds us that close examination of the edges of everyday objects reveals the diffracted, indefinite nature of their borders and observes that it is not that there are no boundaries or that they are blurred, but that they are, however, undetermined (2007:380), adding, "Diffraction marks the limits of determinacy and permanency of boundaries" (2007:381). Feynman explained that our perception of the border between one thing and another is an illusion. In one of his legendary lectures, he questioned boundaries of objects, asking,

> What is the outline? The outline is only the edge of difference between light and dark or one colour and another. It is not something definite. It is not, believe it or not, that every object has a line around it! There is no such line. It is only in our own psychological make up that there is a line (1964:36).

Particles in the Process of Becoming

When experiencing examples of the artworks using diffraction grating, our expectations of fixedness and the defined borders that appear to separate things are challenged. This next example also shows disrupted boundaries and superpositions (See Image 118). Diffraction is grating an apparatus that alters our everyday experience. Light shines through diffraction grating placed over a substrate of a regular grid of black rhinestones and a black marble on an LED panel and the photograph records a moment where the observer's view of the dots is warped and stretched by the diffraction effect. It is an imagined moment in time where particles are in the process of becoming as they pulse out of a stretched, indeterminate wave-like condition evolving to form discrete, individual particulate forms. When appearing as waves, the edges of this becoming are indeterminate; however, they become more defined as the particles condense and become fixed, appearing as separate entities in the lower half of the image.

Although the black rhinestones are actually static, the multiple, hovering coloured duplicates are elusive and seem active, appearing to reside on shifting layers—the exact location of the spots cannot be pinned down. One cannot distinguish and focus on a single dot because the edge is diffuse and constantly shifting. Equally it is not possible to see where it ends and another begins. It is as if the dots are in superposition; each overlays the other and seems to be in more than one place at once. Moreover, the coloured boundaries of the shapes do not have fixed positions, losing their singularity and

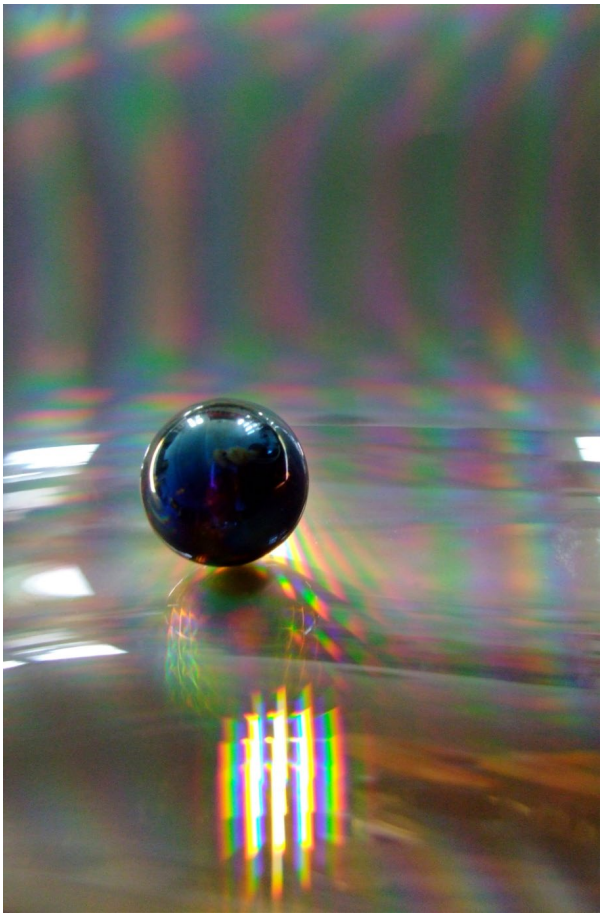


Image 119. Diffraction grating, black marble, sunlight. 2018.

melding into one another in dynamic overlapping patterns, constantly changing with the viewer's movement. This illusion successfully points to the shifting and paradoxical nature of the quantum states that underlie light and matter.

Diffraction Grating Set-Up—Daylight

Diffraction grating is genuinely a baffling material that exhibits the paradoxical qualities of quantum weirdness. In this material investigation, the materials are nothing more than a curved background sheet of diffraction grating and a black marble in daylight. The photograph has not been altered and what it shows confounds our regular expectations. Here, the same black marble sits on top of a fold of diffraction grating rather than behind it (See Image 118 opposite). The diffraction grating unfolds the ambient sunlight into softly-hued spectrum rippled bands. The reflections of the marble are baffling—the double reflection of the jet-black marble disrupts our expectation of what a solid black object's reflection on a shiny surface would be. Ordinarily, there would be a clear point-to-point correspondence—a black circular reflection for a black spherical object; however, there is no point-to-point correspondence. Bizarrely, the two reflections are different and highly complex, bearing an unexpected relationship with the object. Neither reflects the solidity of the marble but is fragmented and multi-coloured. They are not black but composed of a multitude of colours. The edges of the first are disrupted and extended and the second reflection is not black either but is composed of a roughly circular grid-like interference pattern that is bright white in the centre leading outwards to a rainbow spectrum pattern.

Material Investigations—Beam-Splitters: Dichroic Film

Dichroic filters are another device for splitting beams in experimental physics. In this research, extensive material investigations into the properties of dichroic film revealed unexpected illusory qualities and playful colour dynamics, used in many of the artworks to express quantum entanglement. An early set-up included a tangle of wire to explore the notion of entanglement fairly literally. In quantum entanglement, particles can be linked together in such a way that they instantly respond as a pair however far apart they might be. The change made in the state of one particle is immediately reflected in the state of the other (see Chapter 6). Observing the reflections of the wire in the dichroic film revealed that an artistic expression of the phenomenon had emerged into the work. The colours of the reflected entangled wires are *always* in partnership with their complementary colour. Although the colours change as a viewer moves, the complementary pairs always shift instantaneously together—a change in one is always

Image 120: Black ink drawing, dichroic film, LED light. 2017.

accompanied by the corresponding change in the other. They are forever 'entangled' and exist in partnership, correlating with the simultaneous nature of quantum entanglement. As the reflections in the dichroic tubes display unexpected colours when viewed obliquely, they provide an element of surprise, which is key to modifying the RAS.

*

The interwoven processes of the material investigations—looking, doing, making, followed by re-looking, re-doing and re-making—were central to the research and the resulting material investigations became sites to contemplate, identify, unpack and develop the complex themes under enquiry. The results informed both the content and form of the artworks and served to inspire further investigations. Sampling was an opportunity for sustained experiments, closely observing and examining the properties of a variety of materials singly and in combination. Noticing what was happening in the set-ups and their subsequent variations promoted fluency with the materials and revealed surprising and paradoxical optical effects which could be included in the artworks. The discoveries served to bring some of the complex themes, such as quantum entanglement and dissolution of boundaries to material form. The material investigations led to deeper understandings of the quantum questions and contributed fresh angles and new forms to the existing body of knowledge of both the materials themselves and expression of the mysteries at the margins of existence pertinent to this research. These discoveries are incorporated into resolved artworks so that others can share the experience.

The photographic record of the interrogations resulted in a dataset that served as a further site for observation, reflection and interrogation. This record enabled the material investigations to evolve and led to developing new directions. It also provides a non-verbal contribution to the knowledge gained and is recorded in the photo essay accompanying this text.

Chapter 9 follows and examines stages in the development of the several lenticular series as an example of how the application of artistic process and the textile methodology of weaving and braiding together the many themes and artistic processes generated new knowledge.

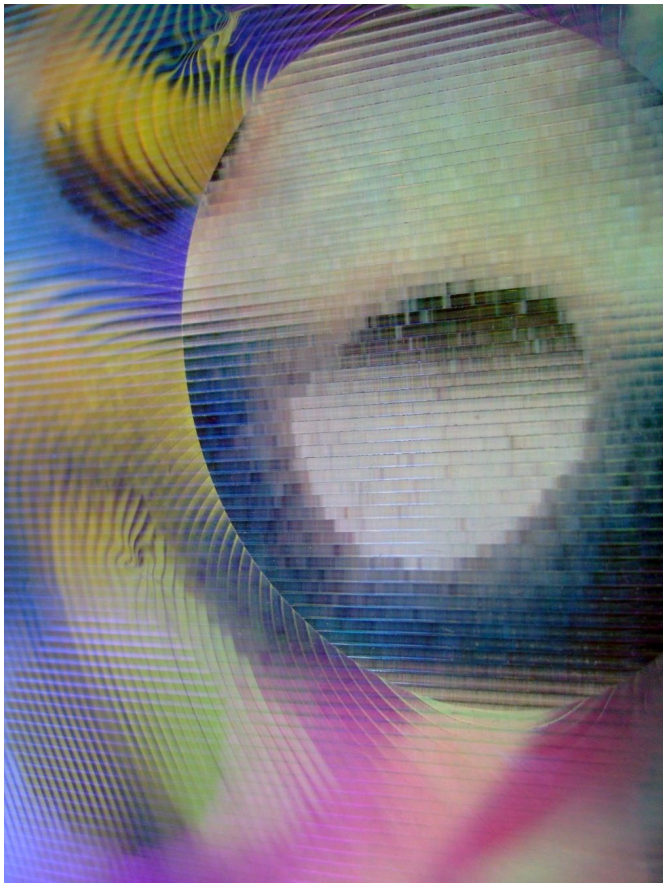


Image 121: Lenticular photograph, dichroic film. 2021.

Part IV—Making Material

Chapter 9
Process—Lenticular Series

This chapter illustrates some of the artistic and investigative processes involved in this research by focusing on one particular medium, in this instance, lenticular photography which was initially used for its potential to explore and present the theme of bridging dualities. Considerations of the quantum notions of particle/anti-particle also contributed to the thinking behind the creation of these works. Lenticular photography folds together two or more images concurrently by interlacing dual versions of an image (a positive and its negative). A print is laminated to a specialised lens which 'decodes' the interlaced images.

Several stages in the enquiry are considered below to highlight some of the processes. Analysis of the investigations led to discoveries that drove the direction of the research; for example, probing the process of interlacing and having control of the technical process in the studio led to exploring ways of applying lenticular photography to the themes of unifying dualities and wholeness. This is followed by a discussion of how the technical investigations enable the limits of the process to be pushed and how this unexpectedly linked back to the earlier material investigations into moiré effects which led to a new articulation of David Bohm's *holomovement* (see also Chapter 7).

Textile Notion #8: Interlacing

Interlacing: A textile term that indicates ordered entanglement. It means to unite by (or as if by) lacing together: interweave, intermingle, intertwine, blend, or to vary by alternation or intermixture.

The etymology of interlace is from old French 'entre' meaning 'between' and 'lacier' meaning 'to lace', 'to tie, 'to entangle'.

Lenticular Photography—Technical Factors: Interlacing

A predecessor to lenticular printing was *tabula scalata*, a popular novelty in late 16th century England. Two images were divided into strips and placed on different sides of a corrugated support. Each image could be seen from a different angle, the other being

hidden by the folds in the corrugation. A similar but more refined effect is created by lenticular photography by using specialised software to splice two or more contributing

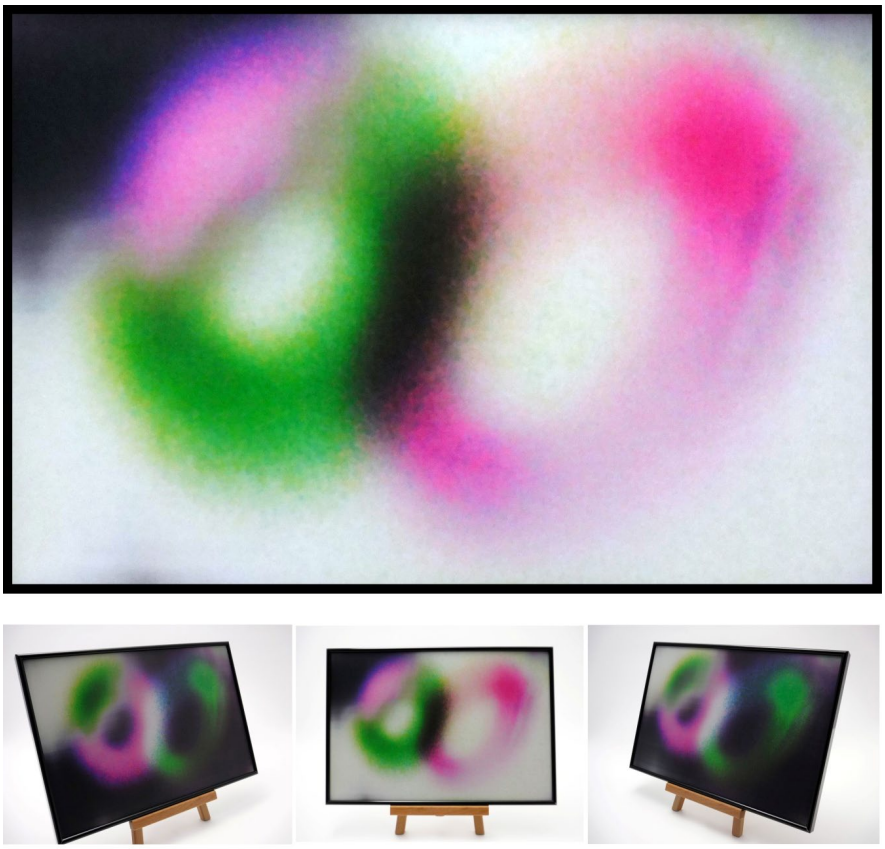


Image 122: Lenticular photograph. Below: three views of same photograph. 2019.

images into thin strips. These are then interlaced, printed and laminated to a corresponding ribbed lens grating. A lenticular lens is an optical apparatus that diverts the path of light, the shape of the angles of the corrugated ridges are designed to refract and direct light waves in opposing directions so that each image emerges independently from the whole.

Having Control of the Lenticular Process

As working experimentally required repeated sampling and constant adjustments, there was an inevitable requirement for multiple prints, making it a costly process when using a specialist lenticular print company. Making the prints in the art studio gave control over the sampling process. Repeated trial and error enabled the limits of the process to be pushed towards technical innovation, leading to novel uses, ideas and unorthodox ways of using lenticular prints (see below).

Lenticular Photography to Unify Dualities

In lenticular photography, different interlacing formats produce various types of movement, including two-way flip effects which are ideal for the purposes of this research, firstly, for questioning viewpoints and, secondly and more aptly, for creating visual experiences that t hold opposite images but without each cancelling the other out. In creating 'flip' lenticulars, two versions of the same image were interlaced—a photograph (the positive) and its inverse (the negative) so that, for example, black parts of the image flip to white and coloured parts change to their complementary opposite—blue to orange, red to green, yellow to purple and so on. This was an evolution of the use of dichroic film's properties of creating pairs of complementary colours to express quantum entanglement (see Chapter 8).

There are three views of the same artwork opposite (angled from the left, the front and the right) to show the positive/negative oscillation—the duality. The original image was a detail from photographic records of a previous material investigation into the surprising coloured reflections in dichroic film. The rings in the initial set-up were drawings of black circles; however, the reflections in dichroic film create complementary colours, due to the angle of light, which sit side-by-side in the ring-shaped forms in the image. The green and magenta of the rings are juxtaposed, and then, as the viewer shifts position, the colours reverse, each flipping to become its opposite. The black background flips to its negative (white), leading to an experience of fluctuating duality where each colour contains and gives rise to its opposite. As they flip, the rings seemingly switch places.

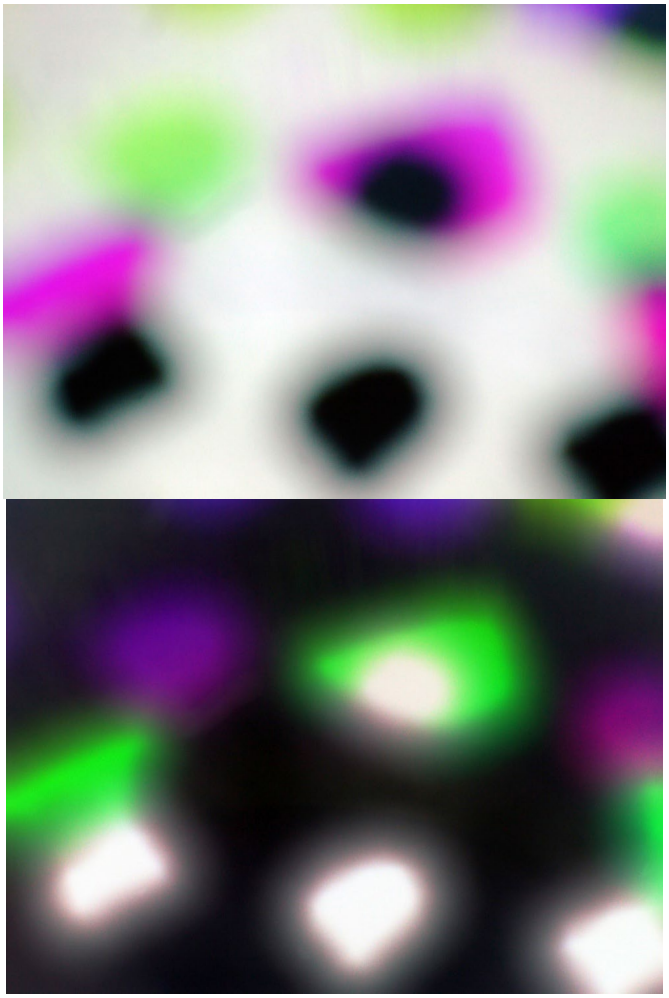


Image 123: Positive and negative images of photograph of black ink drawing reflected in dichroic film. 2019.

This is like the Taijitu (the yin/yang symbol), where each ring in the image is the opposite of the other; however, it also contains its counterpart within itself. The Taijitu is a concept that expresses the paradox of simultaneous unity and duality. It has its roots in Taoism and it is a foundation of Eastern medicine and ancient Chinese philosophy. There is a balance of two opposites in the symbol, symbolised by equal portions of black (yin) and white (yang). Each part contains a small spot of the opposite colour, indicating that it gives rise to the other, signifying that apparently opposite or contrary forces are, in reality, complementary, interconnected and interdependent. This lenticular print expresses this principle. The viewer experiences the shift from one state to the other and back again, each viewpoint holds its own truth—neither is predominant. In this way, the visual ambiguity of the experience of lenticular photographs offers potential for perceptual transformation—along with dualities, certainty and fixedness are questioned, thereby wholeness is expressed.

Lenticular—Perceptual Shift towards Wholeness: Figure/Ground

As we have seen, the dual nature of flip lenticulars is a device that points to the wholeness that underlies reality. It also expresses wholeness by directly questioning the perspective of the primacy of the figure. As the primacy of the figure shifts, the separation between objects is visually questioned, pointing to the wholeness that underlies reality. Fritjof Capra writes that a shift in perspective from parts to the whole is a figure/ground shift that can also be seen as a shift from objects to relationships (see Chapter 3). With Capra's Systems Thinking, relationships are primary as objects are viewed as networks of relationships (which, in turn, form parts of a larger whole) (Capra & Luisi 2014:80). In design, figure/ground can be seen as the contrast between positive space (usually the object) and negative space (usually the background). There are three categories of figure/ground relationships: stable, reversible and ambiguous. The lenticular works for this research are an example of the reversible category because the subject and background flip between one and the other, challenging and disrupting the viewers' figure/ground perception.

As a figure/ground relationship is one of the principles of the gestalt psychology of perception, and as questioning perception is key to this enquiry, gestalt is helpful here in illuminating wholeness. The word *gestalt* means an organised whole that is perceived as more than the sum of its parts, and this principle describes how we separate an explicit figure from a tacit background. Usually, our attention is on the figure as the brain generally determines that it is more important; however, as our focus shifts, the ground (which usually provides context) comes to the fore.

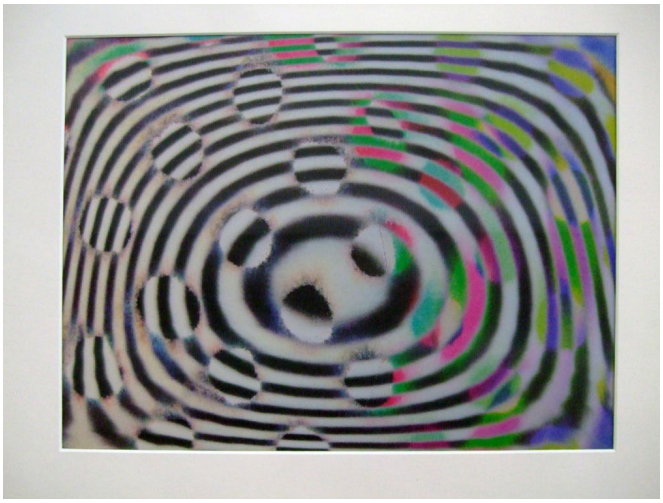


Image 124: Lenticular photograph with warped interlacing. Front view. 2019.

Image 125: Lenticular photograph with warped interlacing. Oblique view. 2019.

Challenging the Limits of the Lenticular Process

Several technical questions arose in mastering the process of lenticular photography for this research. However, the most critical technical issue was determining the correct pitch (number of strips per cm) for perfectly aligning the interlaced photographs with the lenticular grating film. This is crucial and requires sampling for every paper type—it leads to moiré if not precisely correct. Moiré is one of the most common technical problems associated with lenticular prints, the slightest misalignment visibly ruins the flip effect.

Exploiting Moiré

Technically, moiré effects are unwanted and are to be avoided. However, because moiré and interference effects had already emerged as recurring and significant themes through the course of the research, curiosity led to experimentation with the possibility of exploiting and magnifying the moiré effects for artistic advantage. Deliberately creating them brought the optical complexities of interference to dramatic physical form and contributed to a greater understanding of the phenomenon. Moiré 'waves' can be generated in three ways: firstly, by misaligning or skewing the interlaced photograph and the lenticular film: secondly, by altering the pitch of the interlacing across the image, thereby misaligning the width of the interlaced strips and the corrugations in the lenticular lens and thirdly, by 'warping' the interlaced photograph in Photoshop before printing and laminating the lenticular film.

With the first two, misalignment led to straight waves of moiré bands across the whole image. The waves that undulate across the surface of these lenticulars are in a dynamic relationship with the particles in the image motif creating experiences of wave/particle duality. The alternating dark and light concentric rings do not actually exist and are an optical illusion. However, the third process (warping) generated unanticipated effects where dynamic vortex-like forms emanating from a central point were created by the moiré dance. This moiré effect was deliberately activated by manipulating the interlaced image. It creates a kinetic vortex that shifts as viewers move position, introducing the sensation of movement despite their static form and suggesting the constant flux of Bohm's *holomovement* (the process underlying reality for which movement is the primary characteristic).

Depending on their direction of movement, viewers experience either a contracting centrifugal force or an expanding centripetal force of the moiré waves. The concentric circles appear to be propagating outwards as the viewer moves to their right (like the overlapping concentric ripples that occur when a pebble is thrown into a pond), or if they step to their left, the concentric rings appear to be rippling inwards towards the centre.

Image 126: *Beyond Duality #1.* Exterior view. Lenticular photographs, mirror, two acrylic cones. 150mm x 150mm x 150mm. 2021.

Chapter 7 discusses how Bohm's metaphors of the "turbulent mass of vortices in a stream" explain how apparently separate entities relate to wholeness (Bohm 1980:18-19). He explained that a vortex is created as a result of a process and is part of a larger pattern that, although it can be abstracted for examination, is, nevertheless, a flowing part of the whole (Bohm 1987a).

Further Developments of the Lenticular Series

Using the lenticular photographs as a material in mixed-media works took the lenticular investigations in new directions. For example, a series of mixed-media works, *Wave/Particle Duality,* were created to rework the wave/particle motif. At the same time, they reintroduced textile imagery drawn from material investigations into folding and transparency—solarised close-ups photographs of organza fabric. Solarisation is a traditional photographic process to partially reverse an image from negative to positive by exposure to light during development. The images reference Bohm's enfolded/unfolded implicate/explicate orders, their forms suggesting waves and resembling the graphic scientific images of the shape of space-time. These wave-forms emerge from the background, their edges indistinct, hinting at the recurring theme of indeterminate boundaries.

The mini works of the *Beyond Duality* series combine mirrors and lenticular photography. Through both, they express light's paradoxical and bizarre quantum behaviours and question viewers' perceptions. Although they are only 15cm^3 in size, perception of space is altered and challenged in playful ways. In *Beyond Duality I* opposite, mirrors open out the space beyond the frame and the two transparent cones sitting within the cube become a multitude; their reflected conical forms repeat towards infinity, unfolding the perceived space beyond the petite size of the artwork. The interior appears to be much larger than the exterior.

The lenticular prints used in this piece introduce perceptual questions as they line the outer surface of the sides of the boxes and question duality—the 'particles' in their images flip between a colour and its negative. Furthermore, close observation reveals that the reflections of the lenticular print of black and white dots on the floor of the cube are not the same in all four mirrors Curiously, in two of the mirrors, the colours in the reflection are the inverse colours of the original floor; one sees the original and the reversed reflection simultaneously. Hence, a white circle has a black reflection which disrupts the usual point-to-point correspondence of a reflection, questioning the accuracy of the viewer's expectation and perception. Transparent acrylic cones sit within the mirrored space and smaller and more brightly coloured spots are reflected up into the contained space of the

Image 127: *Beyond Duality #1*. Interior view. Lenticular photographs, mirror, two acrylic cones. 150mm x 150mm x 150mm. 2021.

transparent cones from below. These 'particles' appear to have their own movement, altering as the viewers shift their viewing position. Furthermore, the shape of the cone stretches and distorts the shapes of smaller, highly coloured dots, presenting the possibility of the simultaneous co-existence of both wave and particle and alluding to space-time. The dynamic relationship between viewer and artwork reflects the inseparability of subject and object revealed by quantum physics.

Fixed perceptions are challenged in several ways by these artworks, all suggesting that reality is not what it seems. Firstly, they ask about the volume, questioning the apparently larger interior of the small exterior. Secondly, our sense of movement is challenged and thirdly, the perceptions of the oscillating colours are not fixed, also, some (but not all) of the reflections inside the cube counter expectations by being reversed.

It is worth remembering here the role that surprise and novelty play in altering beliefs and perception via the RAS—what we perceive is dependent on prior beliefs and experiences but is altered by new experiences and new pieces of information (see Chapter 3).

The series of investigations of the nature and possibilities of lenticular photography led to works that further illuminated the themes in question in this enquiry. In particular, the dual nature of the media was instrumental in promoting understanding of the nature of light and the ability to create artworks that unify polar opposites and point to wholeness. Exploiting this material's technical properties led to a new way of using it, such as generating the dynamic moiré vortex artworks that express Bohm's theories of the holomovement.

Many materials underwent similar degrees of investigation to lenticular printing, each requiring different approaches and generating different results and outcomes—all illuminated aspects of the nature of light. Each became an apparatus for revealing light's many properties and contributed to furthering understanding of the nature of light and the consequent themes. The discussion of the artistic practice for this research continues in Chapter 10 which records some of the resolved works and immersive installations created during this project and how they synthesise both the entangled themes and the discoveries about light and the various materials investigated through this research.

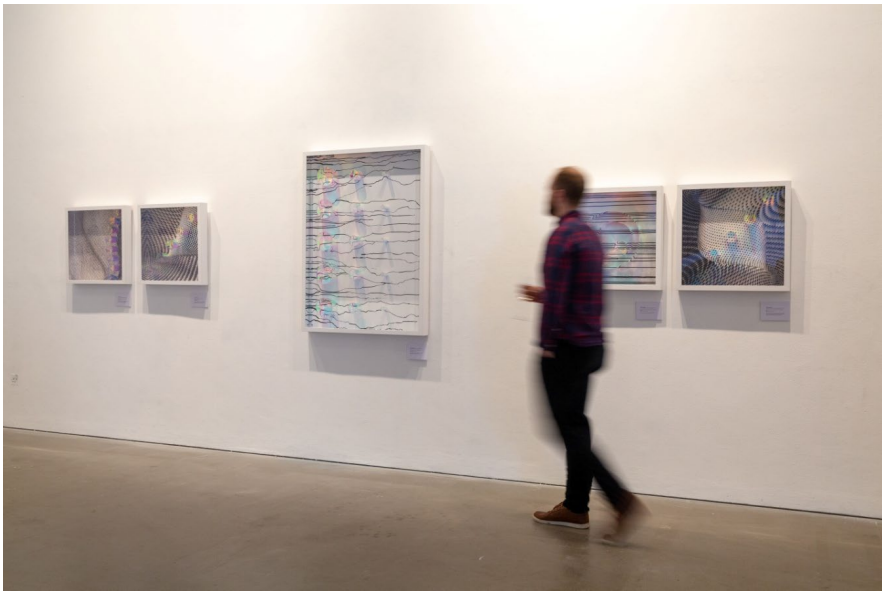


Image 128: Installation view. Arnolfini, Bristol. 2019. Photograph Naomi Wood.

Part IV—Making Material

Chapter 10
Resolved Outcomes

More than thirty series were created during the course of this research. As there is no space here to discuss all the explorations and findings four works have been selected to represent the whole body of work. As well as describing what a person would see and experience if standing in front of each piece, the thinking and artistic process behind the creation of each piece is considered together with an explanation of how it expresses the entangled themes embedded within it that emerged from the study of the properties and nature of light. The unique forms within these works were developed through the investigations into optical materials more commonly seen in physics laboratories. This research discovered that, by their nature and physical properties, these materials can interrogate the areas of philosophical enquiry, for example by disrupting dualisms and questioning boundaries and viewpoints.

The artworks stimulate an 'alethic' gaze (see Chapter 3) and provide unexpected and unfamiliar sensory experiences that impact the RAS (see Chapter 3) because their novelty interrupts our expectations of what we see (Seth 2018). The works created impart knowledge implicitly through the non-verbal language of art, challenging prior fixed beliefs, viewpoints and assumptions at a subliminal level and are thereby sites for augmenting and altering perceptions of the world. By actively questioning the viewer's perceptions, the aim is for the artworks to act directly on the perceptual apparatus of the brain, loosening fixed beliefs based on a dualistic, mechanistic and fragmented worldview and enabling a shift in perception towards ideas of wholeness, interconnectedness and unification of opposites.

The optical illusions that the works present challenge the belief that we are separate. I concur with David Bohm that our sense of separateness *is* actually the illusion (1980:1-2): ultimately everything is interconnected—we are not isolated individuals and cannot step outside the whole. A central underlying theme for Bohm is the "unbroken wholeness of the totality of existence as an undivided flowing movement without borders" (1980:172) and his theory of the Implicate Order connects everything with everything else. In response, I argue that understanding our interconnectedness with the whole of existence spurs us to act with a greater sense of responsibility and awareness.

Image 129: Installation view A&D Gallery. *Indeterminate Interface* series. 2015.

Artwork 1: *Indeterminate Interface* Series

The *Indeterminate Interface* series (see Images 129, 130) is usually shown as a group when exhibited. Several printed prism-like acrylic blocks sit on a row of small shelves and mini spotlights direct white light into the sides of the blocks. Rather than white light, coloured light spills out onto the walls behind the pieces. The colours mysteriously appear as if from nowhere. Surprisingly, the colours bear no relationship to the colours of the images printed on the blocks of, say, a close-up of red organza cloth. Turquoise light emerges from the corner of one piece, then extends and blends with the pink light shining from the corner of the next block. A symmetry links one block with the next, creating a visual chain that oscillates between the insubstantial luminosity of the coloured light and the solid but transparent material substance of the blocks and ink.

The indeterminate boundaries giving this series its title evolved from the material investigations into the complex properties of prisms (as discussed in Chapter 8). Pairs of transparent prismatic acrylic blocks were digitally printed on the rear side and sit alongside each other. However, the join between the pairs is almost invisible and conceals a thin sliver of dichroic film. Due to the properties of internal reflection of the prisms and the nature of dichroic film which completely disappears from normal view, colours are reflected off the film and out onto the wall behind. The intensity gradually diminishes and fades into the background as the reflections extend from the confines of the block. This is in contrast to the definite hard edges of the rectangular frames of the printed acrylic prisms.

The study of quantum light reveals that there are no boundaries between objects and this is visually expressed and questioned here. Physics teaches that there are no sharp edges and optics reveals that rather than a defined boundary, what one sees is a series of light and dark bands (a familiar diffraction or interference pattern); the boundaries between object and surroundings are not determined either ontologically or optically. The boundary of each block is questioned, asking exactly where the interface between the object and the environment exists. Is it the fading edge of the light, or the hard-edged frame of the prism? The dual boundaries suggest that the interface is both an edge and a zone at the same time—the pieces are both contained and not contained simultaneously, presenting a visual example of "both both/and and either/or" (Ascott 2005).

Both Richard Feynman (1964) and Karen Barad (2007:156) remind us that, at the interface between things on an atomic level, it is impossible to determine how many atoms belong to a hand or a coffee mug, for example, because the edges, interfaces, or boundaries between objects are intrinsically linked and are indeterminate. Feynman also reminds us that the idea of boundaries is man-made. Because boundaries are created

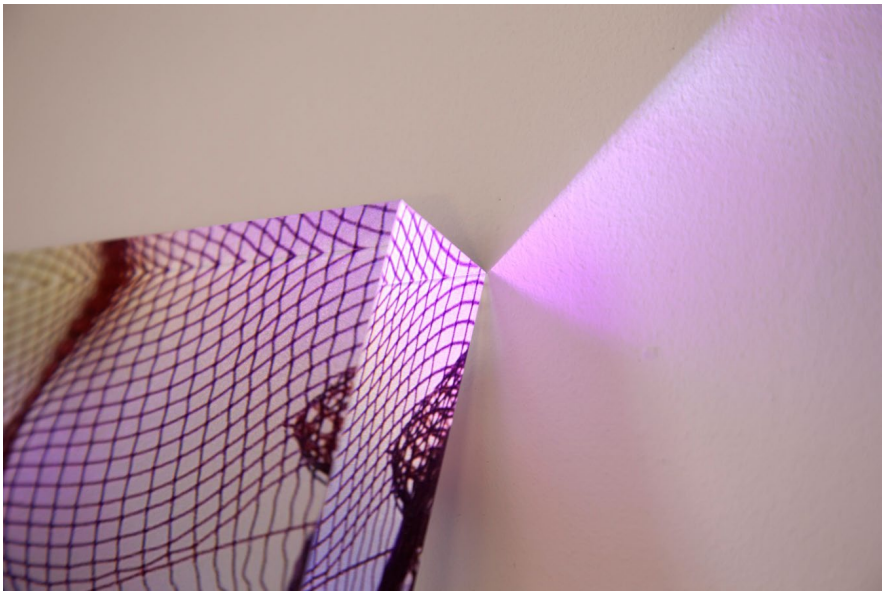


Image 130: *Indeterminate Interface #3*. Detail. Photograph Ibolya Feher. 2015.

conceptually through language, there are many parallels between the framing of things and naming of things. Both are instruments for creating convenient boundaries, as quantum physicist Shantena Sabbadini observes in his guide and interpretation of the *Tao Te Ching*: "With names, 'things are born'" (2013:35). He draws many correspondences between quantum physics and the teachings of this ancient text, stating that the emergence of the fundamental duality of subject and object (both co-emergent in a process of constant creation) corresponds to 'naming'. He observes that,

> ultimately, reality does not consist of things and of individual beings: we live in a named world…The 'nameless' is the undifferentiated, the primordial unity, the *unus mundus*. Naming is the act by which out of the undifferentiated arise subject and object, consciousness and world—and thence unfold the 'myriad beings' (2013:36).

Once something is framed or named, it becomes bounded, however, Lao Tzu taught that the exception to this is the Tao which is the undifferentiated background of existence that precedes or transcends the duality of subject and object (Sabbadini 2013:21, 36). The opening lines of the *Tao Te Ching* state,

The Tao that can be told
is not the eternal Tao.
The name that can be named
is not the eternal name.

The Tao is both named and nameless
As nameless it is the origin of all things
As named it is the Mother of 10,000 things
(Translation: Dyer 2007:2)

The paradoxical juxtaposition of dualities is a central device throughout the *Tao Te Ching* used to point to the indescribable. This has been a useful model for this research.

In addition to engaging the material qualities of prisms, dichroic film and light, the *Indeterminate Interface* works emerged as a result of contemplations on several of the themes being questioned in this research. Beyond questioning boundaries, they physically express these themes, including examining the crease between form and no-form, the relationship between an object and its environment, the interface between Bohm's implicate and explicate orders and aspects of quantum uncertainty and indeterminacy (Heisenberg 1927; Prigogine 1997).

Artwork 2: *Unfolding Light and Space* Series

In seeing one of these works, viewers might ask several questions of the dualities they experience:

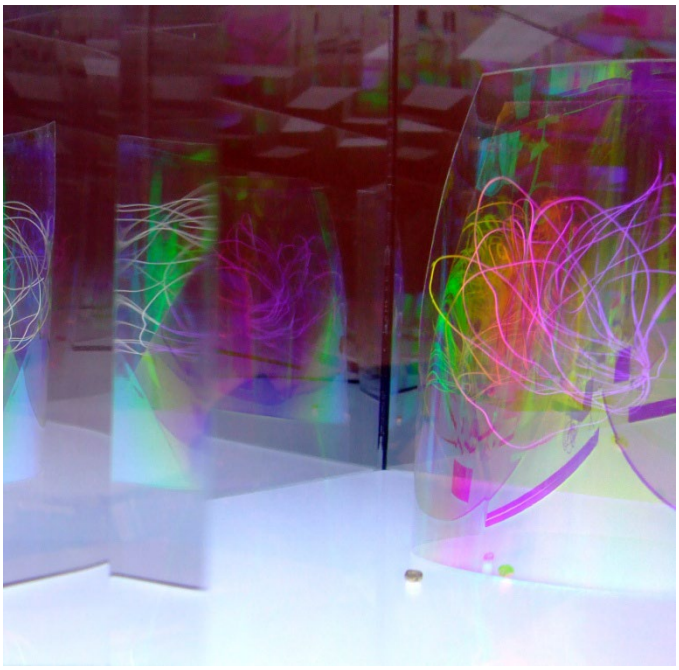


Image 131: *Unfolding Light and Space #4.* Detail view. Two-way mirror, prisms, dichroic film, wire, beads, LED light. 2015.

- Is the space I see small and bounded by the volume of the box? Is it infinite as the reflections suggest? Is it both tiny and infinite at the same time? Exactly what dimension of space is being expressed?
- Is the mirrored cube transparent, or opaque, or is it both at the same time?
- What is real and what is illusion? Can it be both at the same time?
- Objects that are black one moment appear brightly coloured the next. Are they black or coloured, or both at the same time?
- Some elements firmly exist but also disappear and reappear. Are they fixed or indefinite, or both at the same time?

Most pieces in the *Unfolding Light and Space* series are 25 cm half-silvered mirror cubes, lit from below and containing a variety of materials (See Image 131). Due to the properties of the half-silvered surface of the cubes, one experiences a dual play on transparency and reflection, i.e. one can see into the box from each side but not all the way through and out of the other side. The mirrors repeatedly reflect the light and objects inside the boxes so that, paradoxically, the smallness of the cube multiplies out towards infinity.

A key intention in making the *Unfolding Light and Space* series was to interpret and synthesise Bohm's use of the textile metaphors of the unfolding and enfolding of the explicate/implicate orders (see Chapter 7). Moreover, the notion of folding is brought to the realms of light and space—a novel application for folding. In the dynamic interplay between the physical objects in the box and the visually busy but virtual space behind the mirror, one sees an unfolding origami of reflected images with no actual substance. This illusion unfolds the perceived volume of the space towards infinity and questions the substance of reality.

Infinity Mirrors

When looking at the artwork, one does not see one's own reflection as expected; instead, one sees uninterrupted abstract, imaginary realms suggestive of landscapes, cityscapes or other worlds. The use of half-silvered mirror allows the viewer unfettered access to these views, which are not interrupted by one's own image, as they are in Yayoi Kusama's *Infinity Room* and *Mirror Room* installations. For example, along with her use of dots and 'infinity nets', these are materialisations of her hallucinations and psychological experiences and are a highly personal expression of infinity (Kusama 2013:51). With her works, viewers not only encounter Kusama's inner world, they always see multiple reflections of themselves interrupting Kusama's wonderland (See Fig. 17 below).

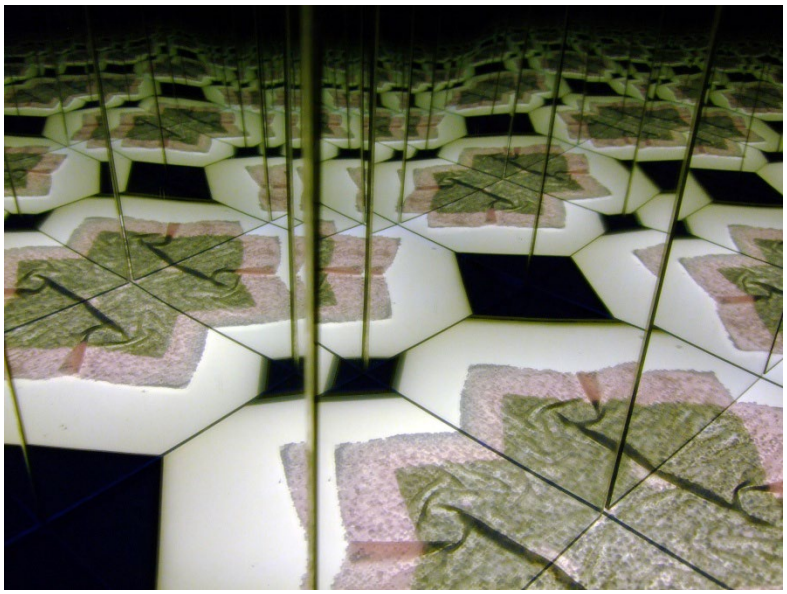


Image 132: *Unfolding Light and Space #4.* Two-way mirror, dichroic film, wire, beads, LED lights. 2015.

Figure 17.
Mirror Room (Pumpkin) 2008.
Yayoi Kusama.
Photograph Peta Jacobs, 2015.

With the right lighting conditions, half-silvered mirror is both transparent and reflective at the same time and the cubes in this research are constructed from two-way rather than plain mirror, thereby presenting an unusual relationship with the nature of mirrors. The resulting complexity of this optical playfulness questions what might be beneath the surface of reality, the world behind the looking-glass. This phenomenon is clearly understood by artist Josiah McElheny who also uses half-silvered mirror. For example, in his installations in *Endlessly Repeating Twentieth Century Modernism,* one of his "infinity studies", highly reflective glass objects sit behind a two-way mirror. He also observes that, as our everyday experience of reflection includes reflections of ourselves, we have a sense of missing ourselves when encountering the reflectivity in this work, creating a subconscious confusion (cited in Nery 2010:160). In the *Unfolding Light and Space* series, this subconscious confusion promotes a shift in perception in the RAS. The expansion of the space within the cube gives an experience that could lead to opening up our thinking and consciousness beyond the confines of what we are familiar with.

Questioning Perspectives

Prisms and mirrors used together in the *Unfolding Light and Space* series reconfigure the viewer's perception of perspectives. Since the Renaissance, traditional painters have employed fixed-point perspectives, on which, holistic architect, Juhani Pallasmaa, writes,

> The invention of perspectival representation made the eye the centre point of the perceptual world as well as the concept of the self. Perspectival representation itself turned into a symbolic form, one which not only describes but conditions perception (2005:16).

I agree that this is the case and argue that the works in this series challenge perception that has been conditioned by a fixed perspective because they present complex co-existent altered and layered perspectives that serve to challenge usual experiences of fixed perspectives in several ways. Firstly, the transparency of the prisms distorts the sense of depth and trajectory by setting up internal reflections within themselves. Secondly, the spatial densities of reflected images within the prisms contrast with different

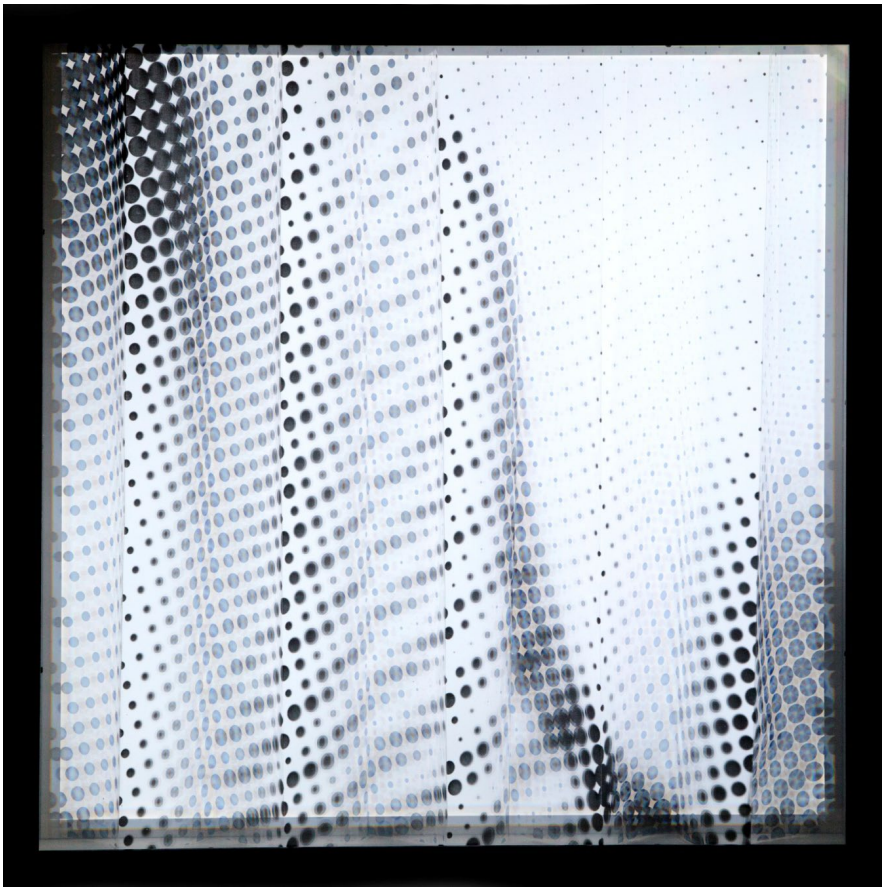


Image 133: ***Unfoldings—Implicate/Explicate #1.*** **Pleated laser print on acetate, diffraction grating, mirror, frame, LED panel. 2016.**

spatial perspectives created by the repeated reflections of the mirrors that create the origami world inside the vitrine. Thirdly the cube sits within yet another perspective of the outer environment of the room. Pallasmaa discusses similar effects created by transparency and reflection in new architecture in *Eyes of the Skin: Architecture and the Senses,*

> Transparency and sensations of weightlessness and flotation are central themes in modern art and architecture. In recent decades, a new architectural imagery has emerged, which employs reflection, gradations of transparency, overlay and juxtaposition to create a sense of spatial thickness, as well as subtle and changing sensations of movement and light (2005:32).

Artwork 3: *Unfoldings—Implicate/Explicate I*

This next artwork (See Image 133) is a black laser print on pleated, clear acetate which sits within a box frame with mirrored edges, the front surface is faced with diffraction grating. The parallel mirrors in the frame extend the image beyond its edges out towards infinity, once again questioning boundaries and defying the limits of the frame. The image is a wave-form composed of a series of small but variously-sized dots representing particles, giving the viewer yet another experience of wave/particle duality.

Words are inadequate in conveying all the themes embedded in this artwork. However, by employing several artistic devices, this artwork successfully presents them visually, expressing themes such as unity from multiplicity, indeterminate boundaries, wave/particle duality as well as pointing to wholeness and connectedness. Moreover, this artwork depicts David Bohm's theories of the dynamic process of the holomovement and the implicate/explicate orders. It is one of the most successful artworks that not only express baffling quantum characteristics such as superposition but demonstrates and gives an experience of them.

Pleated Acetate

Although the vertically pleated acetate has been printed solely with black ink, a surprising variety of soft colours hover around the black spots. They are created by the diffraction of the different wavelengths that compose the white light shining through from the LED back panel diffracting around the edges of the spots. Pleating the laser print both physically combined a folded textile process and referenced Bohm's theories of folding. In his descriptions of the edges of reality, he argued that, at the quantum level, matter unfolds from an implicate order, becoming manifest in the explicate world we experience (see Chapter 7). Although static, the kinetic quality of this artwork suggests the movement that is key to Bohm's theories of the holomovement between the implicate and explicate

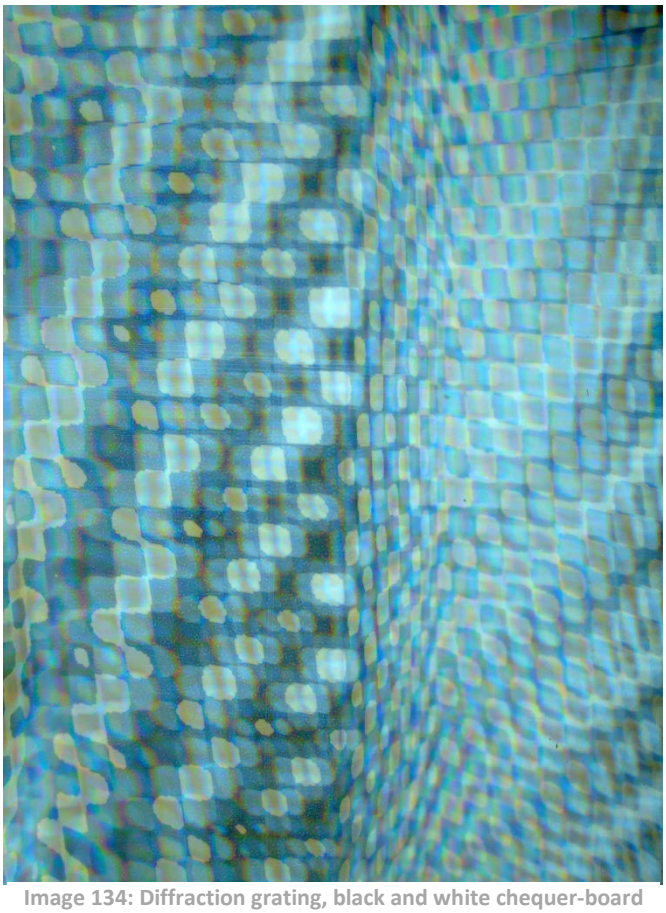


Image 134: Diffraction grating, black and white chequer-board print, LED light. 2016.

orders. In a novel use of diffraction grating, the variation in distance from the crest to the valley of the pleats alters the degree of diffraction of the spots on the print. The spots in the valley of the pleat being further away are diffuse and shifting, whereas the spots at the crest of the pleated wave are more defined and fixed. This indicates and gives expression to a change from one state to another, from the implicate order to the explicate order, the movement from borderless interference waves to bounded particles.

Indefinite Boundaries

These ethereal ghost 'particles' lift off the printed surface, apparently existing in thin air. They overlay each other in subtle, soft hues of blues and oranges to create patterns that shift as the viewer moves position. The colours and patterns the viewer sees are interference fringes due to the diffraction grating unmasking the wave-like nature of light itself. The Op Art paintings of Bridget Riley are called to mind. Riley developed her art by studying the optical mixing of Seurat's paintings (Courthauld 2015); however, here, rather than the crisp edges of Riley's spots, there is a multiplication and divergence of the particle-like elements in the installation. The edges are shifting, imprecise and ill-defined, eventually separating off altogether into increasingly diffuse virtual spots that appear to lift off from each other to reside on dimensional planes of their own. It is impossible to determine the edges of their becoming and it is impossible to determine exactly where they reside in space—where they begin or end. The edges are not precise, and, more than that, they are not fixed as they shift around as one alters viewing position, making the boundaries between object and ground indeterminate, suggesting that something else, not immediately obvious, is going on here. The active, entangled relationship between the viewer and the object is made explicit, providing experiences and sensations of synchronism of subject/object dichotomies.

Artwork 4: *Quantum Questions—Unfolding Implicate Order #2*.

A viewer looking at *Quantum Questions—Unfolding Implicate Order #2* (See Image135) sees the abstract shapes and forms that express both unity and a moment of becoming (both key areas of philosophical enquiry in this research). Neuroscientist, Eric Kandel, explains how perception is more successfully impacted by abstract art than by figurative art, which supports the assumption that works for this research influence perception through the filter of the RAS of the viewer. He writes,

> While we are just beginning to understand how our brain mediates our perception and enjoyment of art, we do know that our response to abstract art differs significantly from our response to figurative art. And we know why abstract art can be so successful. By reducing images to form, line, colour, or light, abstract art

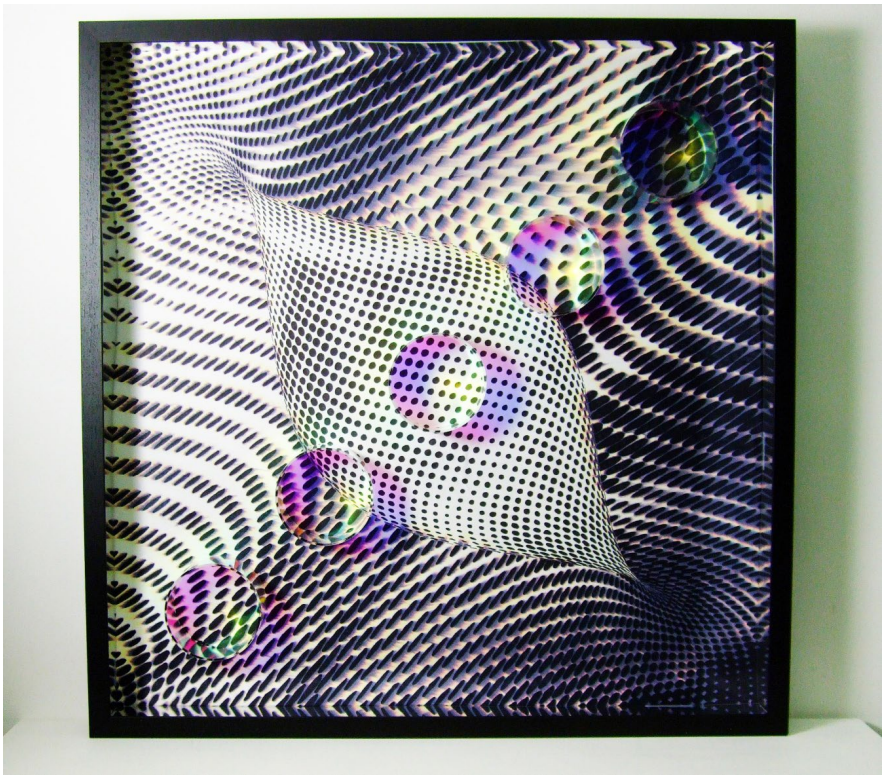


Image 135: ***Quantum Questions—Unfolding Implicate Order #2.*** **Shoji paper, dichroic film, black ink drawing, mirror, frame. 940mm x 940mm x 80mm. 2018.**

relies more heavily on top-down processing—and therefore on our emotions, our imagination and our creativity (2016:58).

As the title suggests, this artwork incorporates and gives expression to Bohm's implicate order—a lozenge-shaped form unfolds and emerges from the background order. Both object and background are formed of dots—some round, others elliptical, some with defined edges and others with diffuse edges. A row of five three-dimensional dichroic rings crosses the surface of the drawing, the dichroic film reflecting the black dots with surprising colours.

Employing Art and Design Principles to Depict Unity

Artistic expression can articulate ideas and feelings through a visual language comprising a vocabulary of elements such as line, colour, value, texture and shape, along with a syntax of guidelines (rather than strict rules) such as unity, scale, balance, rhythm and emphasis (Lauer & Pentak 2008). In this research, this language of artistic devices which engage the principles and elements of art and design is communicated through a variety of media and processes.

Commonly, unity is achieved through a composition of repetition of elements (shapes, linear features or colours) that create a unified pattern. Studies in perception (e.g. the gestalt theory of visual psychology) show that a viewer attempts to organise elements, find coherent patterns and unity. This is because the brain looks for similar elements in order to perceive order and coherence rather than seeing unorganised chaos, for example, by grouping objects that are close together or forming a constellation. Likewise, negative (or empty) spaces can also appear to be organised.

Unity is a fundamental design principle and the aim of this and other artworks is to present and emphasise unity and wholeness. In design, an "important aspect of visual unity is that the whole must predominate over the parts" (Lauer & Pentak 2008:30). Although there is a difference between visual unity (where the eye discerns the harmony or congruency) and intellectual unity of ideas and themes, both are brought to bear in *Quantum Questions—Unfolding Implicate Order #2* where the visual unity created by the artistic devices reflects and supports the intellectual and philosophical questions. Here, in this artwork, the smaller parts of the composition yield to the organisation of the larger pattern, and, to enable an experience of unity, there is a congruency, agreement or harmony between related visual elements. The repeated marks of a subdued palette unify the composition, which is made only from dots of varying sizes and shapes (circles and ellipses), a gestalt prioritising the whole over the parts.

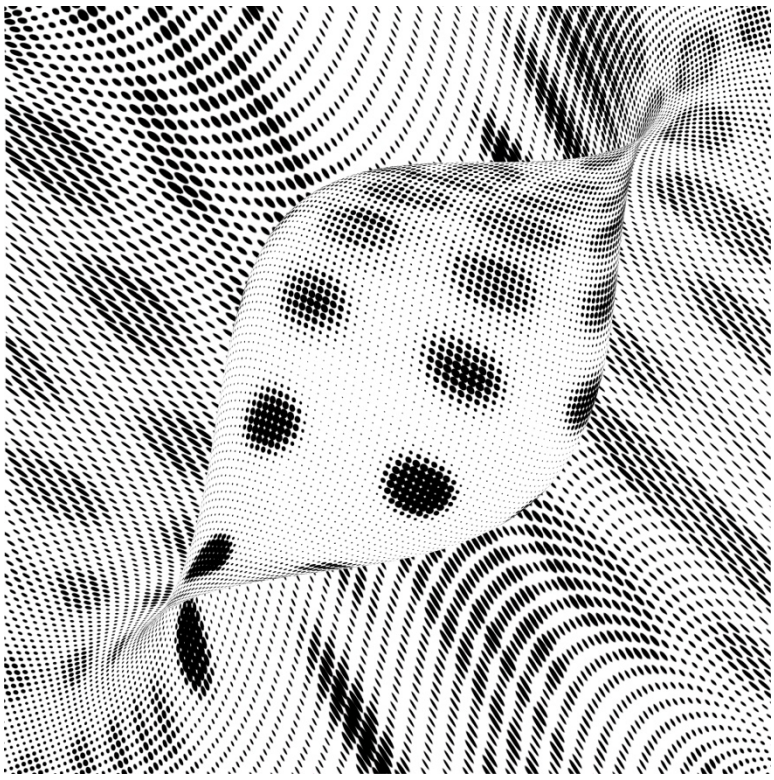


Image 136: Photoshop manipulation of photograph with halftone and warp processes. 2018.

Another widely used device for creating unity strongly featured in this artwork is the repetition of elements, such as colours, textures, direction, angles or shapes. This is evident in the repetition of the circular and elliptical shapes that orient to direct the eye, giving the illusion of the emergence of the three-dimensional lozenge-shaped form—no drawn linear lines define the shape of this form. Although the background appears to be composed of repeating concentric lines, these too are created by the placement and direction of the dots and the regularity of empty negative spaces between.

Symmetry is another design device that creates visual unity and along with the horizontal and vertical lines of symmetry created where the mirrors reflect the drawn marks, the image is symmetrical along the diagonal. The use of the diagonal is a commonly used device in art and design composition to denote movement (Lauer & Pentak 2008:134) and is used here in response to Bohm's theories where he proposes that movement is fundamental to the holomovement process of the implicate and explicate orders (see Chapter 7).

Boundaries

Along with the reflections in the mirrors disrupting the boundary of the frame, suggesting a continuation of the image beyond the frame, contrasting treatments of the drawn marks creating both the central form and the background also highlight the question of boundaries. Two types of marks were made with different qualities of black ink to create a variation in texture that defines and visually 'pushes' the unfolding form out from the background surface. The constituent colours making up one of the inks bled out from the edges of the black ink dots forming the background creating diffuse edges. On the other hand, the crisp dots of the central form remained within their boundaries as they were drawn with permanent ink.

Warping an Inverted Fold

Addressing the quantum considerations of boundaries and Bohm's implicate/explicate orders inspired the design for the composition of the whole image which was created by using a Photoshop transformation warping tool. Before the manipulation, the original image was a continuous flat surface comprised of a series of dots. This was then warped to the degree that it was turned completely inside out, producing a totally inverted fold so that this new object was unfolded and born out of its surrounding order and the outcome visually expresses these theories. Potentially, the process could be reversed and the rhombic form could just as easily unfold, disappearing back into the background.

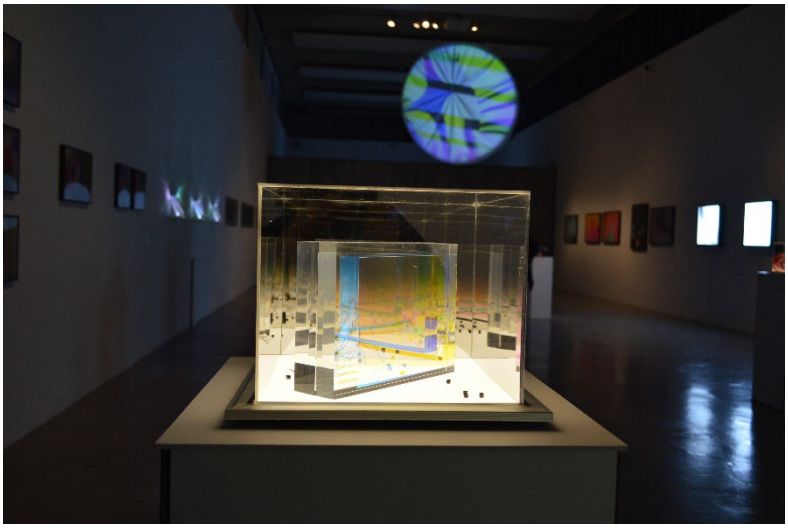


Image 137: U*nfolding Light and Space.* Installation view Quantum Light—Beyond a Crisis of Perception exhibition. 2022. Photograph Amak Mahmoodian.

Summary of the Four Artworks

These artworks address László Moholy-Nagy's question, "Space, time, material—are they one with Light?" (1950) and the deliberately open, speculative initial question for this research which was, What new forms and understandings can an art-based investigation into the nature of light reveal? They also address other questions that arose as the research progressed—what new forms and understandings emerge when engaging the phenomenological characteristics of optical materials used in the two-slit experiments through a studio practice and, could the artistic use of these materials contribute to illuminating the nature and properties of quantum light and the philosophical themes arising from quantum physics?

Many themes emerged, including unifying dualities and the entangled relationship between subject and object; the underlying oneness and interconnectedness of all things and the paradox of unity from multiplicity; and questioning boundaries and expressing and revealing the hidden, immaterial aspects of our reality. The artistic practice enabled their exploration, visualisation and transmission. Each theme was approached in many ways and the findings were entwined, synthesised and presented in several series of artworks.

The four artworks described above all successfully incorporated the breadth and complexity of the entangled themes and phenomenological discoveries gained during the background scientific and philosophical research and the material investigations. Their visual novelty and illusory qualities introduce unexpected and unfamiliar sensory experiences and because they interrupt our expectations of what we see, they impact the perceptual apparatus of our brains—the RAS (Seth 2018). The RAS is the gatekeeper of the sensory input to the brain, the filtered information received through our senses is incorporated by our perception and we interpret what we experience.

Each viewer brings their own interpretations of what they see in these artworks depending on the personal impact of their RAS of their past experiences and beliefs, placing the new information into a personal psychological context. Due to the novel and ambiguous attributes of the artworks viewers frequently comment that they do not know what they are seeing when they experience them. In *Reductionism in Art and Brain Science: Bridging the Two Cultures* (2016), Nobel Laureate, Eric R. Kandel, writes of the reciprocal roles of the artist and viewer with regards to the ambiguity of abstract, reductionist art,

> The viewer responds to this ambiguity in terms of his or her own experiences…For the artist, the creative process is also interpretative, and for the beholder the interpretative process is also creative (2016:20).

He goes on to argue,

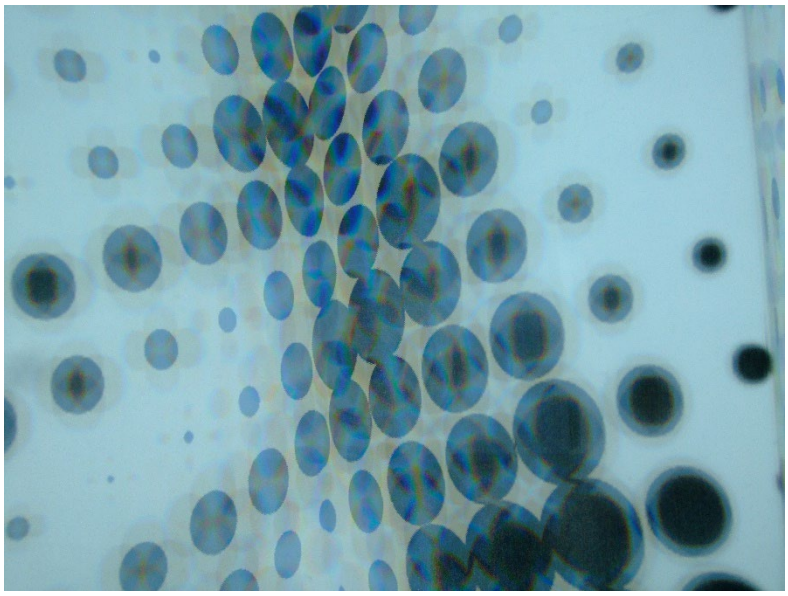


Image 138: Diffraction grating, laser printed acetate, LED light panel. 2016.

> Because the extent of the viewer's contribution depends on the degree of ambiguity in the image, a work of abstract art, with its lack of reference to identifiable forms, arguably puts greater demands on the beholder's imagination than a figurative work does. Perhaps it is these demands that make abstract works seem difficult to some viewers, yet rewarding to those who find in them an expansive, transcendent experience (2016:20).

The illusory aspects and unusual materials composing the artworks created for this research add to the ambiguity, novelty and abstract nature of the imagery, thereby intensifying their impact on the viewers' perceptual apparatus.

The piece that most successfully exemplifies the quantum nature of light is the third described above, *Unfoldings—Implicate/Explicate I*. It not only visually represents properties such as superposition, quantum entanglement and the unfoldings and enfoldings of Bohm's explicate and implicate orders, importantly, it also provides an experiential experience of these quantum properties. Although the drawing creating the was made with only black and white, we see a variety of colours created. However, they do not exist, the phantom coloured spots and patterns are illusions generated by the diffraction interference. They appear and dissolve and they appear and dissolve shift and move in space—it is impossible to definitively locate them. Boundary and location are questioned, they are more than an expression or representation but offer a demonstration of both non-locality and the explicate order emerging from the implicate order that can be experienced by the viewer. David Bohm describes the process as discrete forms that emerge and perpetuate,

> Whatever persists with a constant form is sustained as the unfoldment of a recurrent and stable pattern which is constantly being renewed by enfoldment and dissolved by unfoldment. When the renewal ceases the form vanishes (Bohm & Hiley 1993:357).

The artworks of the *Indeterminate Interfaces* series where coloured light fans out onto the gallery walls, piercing the boundaries of printed blocks that form them. The apparent source of this coloured light is the white light of the mini spotlights. As described in Part III, quantum understandings of light challenge notions of boundary and this installation both visually questions boundary and points to hidden, immaterial attributes.

Applying a methodology of textile thinking was successful in managing and interweaving the complexities and many strands of the research, not only in enabling thinking about the themes but also in the creation and composition of the artworks themselves as was indicated by the use of the textile term folding in the titles of three of these four artworks. This textile term was incoportated in many ways, for example, the acetate sheet composing *Unfoldings—Implicate/Explicate I* was physically pleated and the development

Image 139: *Quantum Questions—Line Interrupted #7*. Forex, calligraphy ink, acrylic, dichroic film, mirror, wooden frame. 2017. Installation view. Arnolfini Bristol. Photograph Naomi Wood. 2019.

of the drawing for the image composing the fourth piece, *Quantum Questions—Unfolding Implicate Order #2* was completely folded in on itself to create the lozenge-shaped form from the background. Notions of (un)folding were applied to domains not normally associated with folding—light and space through the use of prisms and mirrors in the *Unfolding Light and Space* series to question a viewer's perceptual sense and expectations of space and perspective.

Exhibitions

Beyond exhibiting artworks in several joint exhibitions, the works were shown to the public in *Counterpoint* (2015) at A&D Gallery, London and *Edge of Becoming* Centrespace Gallery, Bristol (2015). The final exhibition, *Quantum Light—Beyond a Crisis of Perception,* held at the James Hockey Gallery, Farnham was the culmination of the research and exhibits the work from two standpoints by offering both discursive and immersive experiences to the viewer. Emilie Sitzia argues that these modes of exhibiting are not opposed to each other but are complementary; however, their impacts on the viewer are different. A discursive exhibition disseminates cognitive information and "creates a space for reflection but diminishes the emotional engagement", whereas, she says that immersive exhibitions enable the viewer "to feel rather than solely look" and that, "the art exhibited is not a 'mute' or 'third person' but a firsthand experience/voice for the visitor". She goes on to argue that immersive experiences in museums change who we are, "creating space/time for self-examination and are an ideal environment for transformative learning" (2016).

In a critical reading of discursive and immersive exhibitions, Mark Wigley (2016) explains that, whereas a discursive exhibition interfaces with the brain, an immersive exhibition interfaces with the body and "the logic of the multi-sensory". He argues, in a discursive exhibitions, the subjects [viewers] are isolated from the art objects, physically and conceptually, whereas, "The immersive exhibition or installation represents a loss of this subject/object spacing by using the language of the multi-sensory as opposed to the language of vision…any gaps or sense of separateness are lost" (2016). He poses that a discursive exhibition frames the object, and the immersive exhibition "pushes this frame out of our perception" and that "immersion is experienced as a loss of limits, of lines, of boundaries" (2016). This questioning of boundaries is an apt positioning for this enquiry.

Final Exhibition: *Quantum Light—Beyond a Crisis of Perception*

The final exhibition is shown in two parts which are separated by the *Double Aperture Moiré Wall* which divides the gallery. The exhibits on one side are presented with

Image 140: Double Aperture Moiré Wall. Installation view Quantum Light—Beyond a Crisis of Perception exhibition. Photograph Amak Mahmoodian. 2022.

discursive elements such as labels and wall text creating a separation between the viewer and the art objects and asking for cognitive engagement. Nonetheless, as the viewer experiences their playful, illusory properties, many of the artworks ask for a direct bodily response and could be considered to be mini installations. The space in front of the *Double Aperture Moiré Wall* is dominated by *Quantum Breath,* a large circular particle-shaped projection screen showing a succession of images collated from the dataset which are projected onto the undulating surface of the circular screen. The images expand and contract across the wrinkled surface in a regularly pulsing rhythm. The walls of the gallery are lined by rows of huge reflective silver particles created from mirrored foil, each containing a smaller particle. Due to the asymmetrical planes and wrinkled surfaces of the discs, the reflections of the moiré wall, the gallery space, the lighting and the viewers themselves shift as the viewer moves within the space.

Double Aperture Moiré Wall **Installation**

The combination of *Double Aperture Moiré Wall, Quantum Breath* and *Particle Paradox* references the two-slit experiment, which is central to this research and provides a large-scale expression of the experiments and particles and waves. The experiments demonstrate that the experimenter/apparatus and subject/object are entangled and that there can be no such thing as a detached observer (Barad 2007:14).

The *Double Aperture Moiré Wall* is a huge wall enveloped in layered fabrics that create a moiré effect that spans the whole the gallery. It has two narrow entrances to the space beyond. Just as the two-slit experiments are set up to determine which slit a particle passes through, the viewers choose which of the two narrow openings in the moiré wall they use to enter into the space beyond the wall. Although the wall is static, the moiré patterns dynamically dance across it as the viewer approaches. Moiré is a large-scale interference pattern that challenges perception and provides an experience of movement. However, this is a visual effect and the rippling moiré patterns are not actually there as they are formed and perceived via the brain's perceptual processes.

Beyond Dualities Pavilion **Installation**

Another installation in the exhibition, *Beyond Dualities Pavilion,* was initially designed to be an enclosed mirrored cabin which the viewer could enter and experience repeated reflections of themselves and the artwork in the ceiling in the mirrored walls and floor of the cabin of the cabin in all directions. As the gallery was not invigilated, a walk-through tunnel was more appropriate. Nonetheless, the experience was disorienting—its novelty is designed to impact the RAS of the viewer. The exterior footprint is small, 1.2 metres by

Image 141: Beyond Dualities Pavilion. Installation view Quantum Light—Beyond a Crisis of Perception exhibition. 2022. Photograph Amak Mahmoodian.

3.6 metres, however, due to the placement of the parallel mirrors, the experience of the space inside the pavilion expands in two directions towards infinity. Sensing exactly where the boundaries and dimensions of the pavilion lie depends on whether you are inside or outside the pavilion. Perception is challenged—the space is both contained and not contained at the same time, thereby questioning boundary and suggesting a wholeness that extends beyond the frame of the cabin and that interconnects with everything.

From the outside one can see into the contained space through half-silvered mirrors. One sees multiple reflections of anyone who stands inside the cube and the silver particle discs hanging on the walls of the gallery. However, one cannot see one's own reflection so that the viewers' usual experience of reflection is disrupted. Niels Bohr's theories argue that there is no definite way to distinguish between the observer and the object; here, the viewer becomes the observed and the complex interconnected relationships between subject and object are exposed.

Once inside the pavilion, although the viewers can see multiple instances of themselves in the reflected space that unfolds into the distance, they cannot see through the glass out into the gallery. As they would have looked into the pavilion before they entered, they would have previously experienced the mirrored walls of the pavilion as being transparent. Once inside, although they know that the exterior world is there, they cannot see it, except where they enter and exit the pavilion space. Paradoxically, the pavilion experientially highlights questions of both separation and wholeness—there is and inconsistency between what one expects to experience when looking in versus looking out. When inside and looking into the mirror one feels cut off from the outside. As Capra and Luisi state (2014:10), an integrated whole cannot be reduced to those of its parts; instead, the parts arise from the interactions and relationships between themselves. Inside the cabin, the viewers are required to interact with multiple images of themselves which are constantly changing as they move.

A mixed-media artwork in a lightbox lines the ceiling of the pavilion formed of a print selected from the dataset of linking threads which were manipulated to form a vortex shape (See Image 141). The print is layered with a multitude of dichroic dots which follow the form of the vortex. Bohm used an analogy of vortices in the flow of a river to describe how regions of order could be contained within the continuous flux. Eddies are distinct structures in the whole river and are analogous to the manifestations of the explicate order, the river indicating the underlying processes of the implicate order (Hussey 2020:172). As there is a mirror on the floor, this vortex is reflected into a space beneath the inhabitant's feet, creating an illusory void that many viewers were reluctant to step on

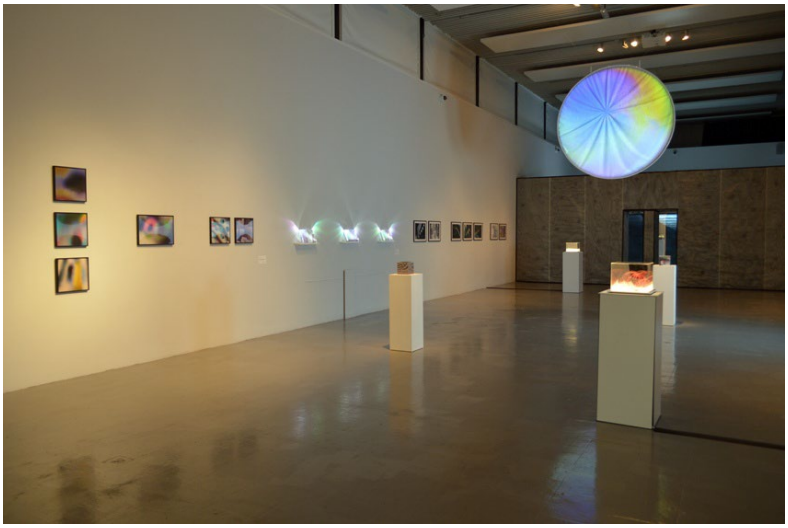


Image 142: Installation view Quantum Light—Beyond a Crisis of Perception exhibition. Photograph Amak Mahmoodian. 2022.

to. They know that the floor is solid beneath their feet but their depth perception senses tell them something different.

Expectations of what we know about reflection are further disrupted because the mirrored duplicates of the dichroic particles change hue as they recede into the reflected distance. When close to the viewer, they appear as magenta pink, but, strangely, change to green and then yellow as the reflections in the mirror recede into the distance. This curious effect was discovered through the material investigation set ups with dichroic film and mirrors.

The viewers exit the exhibition by walking back through the discursive space again and have the opportunity to supplement their immersive experience cognitively with visual and textual information.

The *Quantum Light—Beyond a Crisis of Perception* exhibition is the conclusion to this enquiry. The artworks and installations incorporate and weave together the many themes that emerged as the research progressed. As it was the methodology used to interweave the multiple elements of this research, textile thinking is both implicit through the use of textile metaphors and motifs and is also physically evident in the use of textile processes, such as folding and pleating of the materials used. Moreover, the *Double Aperture Moiré Wall* is a large textile installation exhibiting the dynamic undulations of moiré effects. Although the structure is static, the viewers experience the kinetic movement of the moiré as they approach the wall. This use of moiré responded to Bohm's theories of holomovement. In combination, the parts of the installation, *Double Aperture Moiré Wall, Quantum Breath* and *Particle Paradox* reference the two-slit experiment and present questions of wave/particle duality.

The artworks demonstrate different properties of light, such as reflection in the *Beyond Duality* Pavilion and the nature of diffraction, which is highlighted in works such as *Unfoldings—Implicate/Explicate #1* and *Unfolding Light and Space #5*. In these works, diffraction expresses quantum superposition, disrupting boundaries and articulating edges of becoming.

In response to the quantum 'observer effect', many artworks in the exhibition highlight the entangled role of the viewer and the art object, for example, by entering the *Beyond Dualities Pavilion*, the viewer becomes the viewed. The works shown question perspective and viewpoint. Moreover, they present novel forms and unusual sensory experiences, influencing perception through the RAS.

Image 143: *Unfolding Light and Space #1.* Two-way mirror, prisms, dichroic film, beads, wire. 1200 mm x 300mm x 25.mm. Photograph Ibolya Feher. 2015.

*

It is not possible to discuss all the series created during this project; however, a broad overview was possible through these examples above. All four works were created using knowledge gained during the material investigations. Firstly, the *Indeterminate Interface* series created a play on transparency and reflection by the use of prisms which enabled dichroic film to be hidden from view. Although hidden, it still performed an essential role in questioning the boundaries of the pieces by casting fan-shaped coloured light out onto the walls, seemingly from nowhere. This raised the question of the nature of the interfaces between the artwork and the environment and led to a discussion about boundaries and naming and framing.

The second work, *Unfolding Light and Space: Study I*, also used prisms to playfully question the perception of the viewer. However, the key material used in this work was half-silvered mirror which paradoxically pointed towards infinity within the contained space of the cube. The dual nature of two-way mirror is both transparent and reflective, so, together with other materials, enabled several polarities to be united. This work also further challenged other dualities where things appear and disappear, are black and coloured and are real and virtual. This work also challenges the fixed perspective that has prevailed since the Renaissance and, as with the other works, visually incorporates the theories behind the science of light by addressing quantum questions, such as entanglement and the observer effect.

The third artwork, *Unfoldings—Implicate/Explicate I,* presents an experience of the edges of becoming and quantum superposition. Due to its pleated composition, it is not possible to determine precisely where margins lie. Its creation was possible through understanding gained through the extensive practical investigations into the illusory qualities of diffraction grating. It is one of the many pieces exploring the wave/particle motif in different ways and emerged through contemplation of and intention to illuminate Bohm's theories.

Finally, *Quantum Questions—Unfolding Implicate Order #2* also illuminates Bohm's theories and gives the viewer experiences of the entangled themes of unity, wholeness, holomovement and indeterminate boundaries. The artistic processes in creating the artwork were explained, including creating unity through artistic devices such as repetition, symmetry, colour palette and the use of different inks and using processes in Photoshop software to manipulate the image to create an inverted fold to represent the unfolding of the enfolded implicate order.

Image 144: *Indeterminate Interface*. Printed acrylic blocks, dichroic film, LED spotlight. Installation view Quantum Light—Beyond a Crisis of Perception exhibition. 2022.

The immersive works in the final exhibition were described alongside a discussion of the relative advantages of discursive and immersive exhibitions. Between them, all these works interweave many aspects, ideas and themes that emerged through this research into the nature of light. The discussion of each piece above focused on different features, including artistic devices and processes, the artistic use of materials and how they express and interrogate some or all of the following philosophical themes that thread throughout the research. They highlight the underlying oneness and interconnectedness of all things and represent the paradox of unity from multiplicity. They explore the notion that dualities can be bridged and question boundaries, edges and frames, thereby expressing and revealing the hidden, immaterial aspects of our reality.

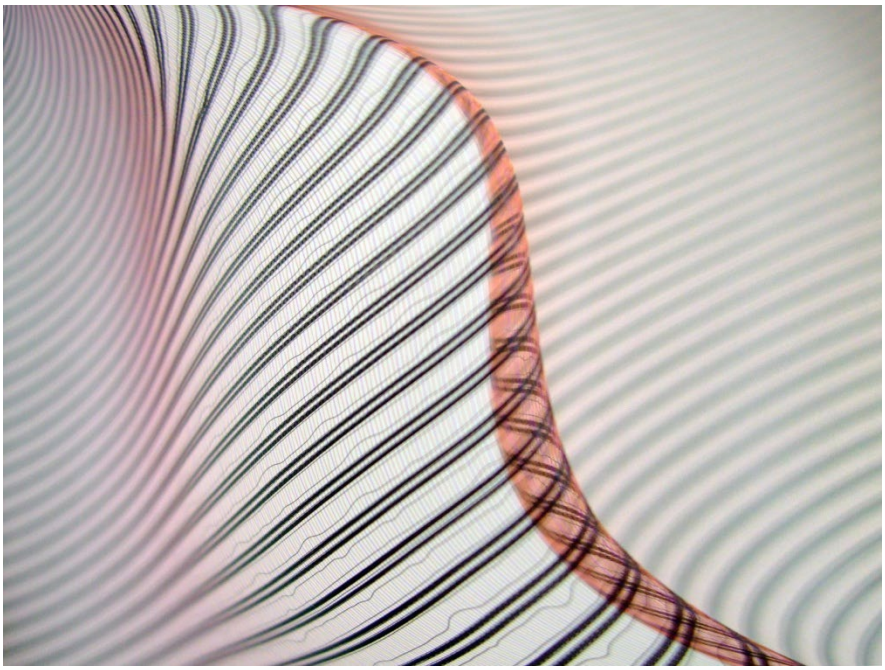


Image 145: Striped translucent fabric. 2016.

Conclusion

Loose Threads and the Whole Cloth

Light is an ideal medium to examine the intriguing aspects of the edges of becoming. László Moholy-Nagy's question "Space, time, material, are they one with Light?" served as a guide and leitmotif for the research alongside the inspiration of the *TRA: Edge of Becoming* exhibition held during the Venice Biennale in 2011. This exhibition and its catalogue essays provided a model for a multi-disciplinary approach and pointed to the initial entry points. Soft textile thinking is an ideal methodology for a multi-faceted enquiry. As well as offering possibilities for non-linear thought, textile thinking provided a framework for a mixed-media approach to making artwork and generated non-local solutions to the material investigations. Pennina Barnett and Claire Pajaczkowska (2007) define textile thinking as "an inclusive mode of thought that weaves, ties and holds things together that makes connections".

Deeply probing the science of light led to encountering the bizarre world of quantum physics which is mysterious, baffling and perplexing, especially to non-scientists. It speaks of the wholeness underlying reality, of paradoxical duality and provides theories explaining phenomena at the edges of becoming—between the seen and the unseen, material and immaterial. Light shows us that reality is stranger than we think it is. As Arthur Zajonc says, "The mysteries of quantum mechanics, its paradoxes, wake us up to the deepest aspects of our world. Light is the bridge between these worlds" (2015:120).

The initial approach to this research was speculative and deliberately open, seeking to find out what new forms and understandings an art-based investigation into the nature of light could reveal. In addition to background studies of quantum theories, an exploration of the material qualities of light through the analysis of the phenomenological characteristics of optical materials was approached in the art studio. This resulted in discoveries that enabled bringing the paradoxical, ethereal quantum ideas to physical form through the use of these materials.

Through the course of the research, it became clear that the two-slit experiments are central to the perplexities of quantum physics. They ask many foundational quantum questions, including whether light and matter are fundamentally formed of waves or are composed of actual, discrete particles (or even both simultaneously) and they serve to anchor the physics and centre the focus of this project. They pose questions of non-

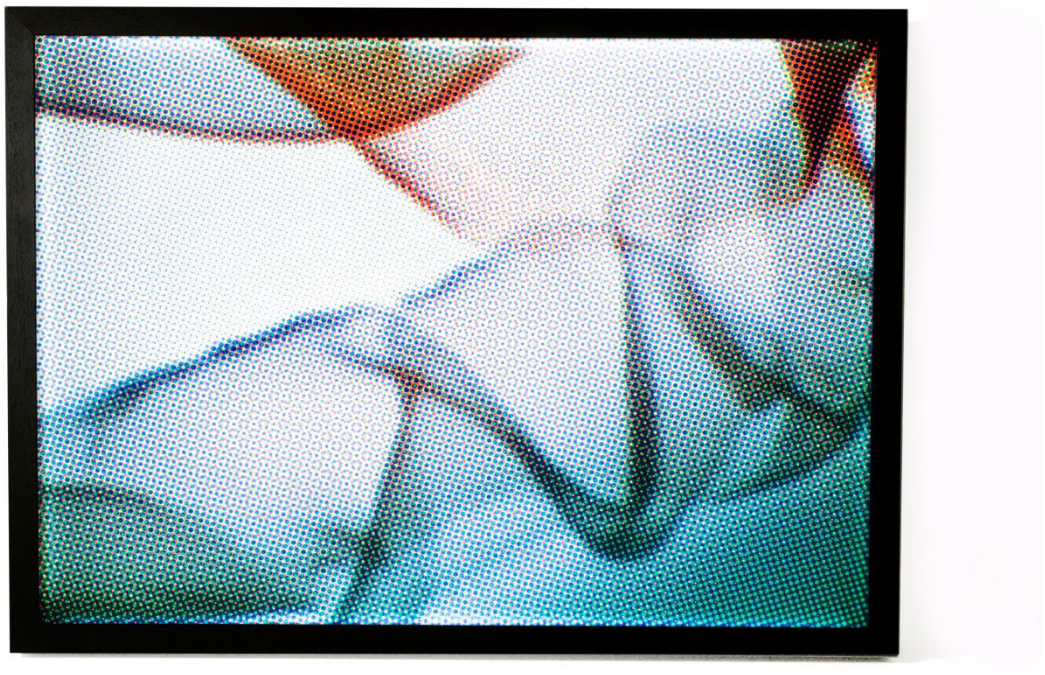


Image 146: *Unfolding/Enfolding—Implicate/Explicate*. LED light panel, prints on acetate three sheets of acetate. 594mm x 841mm x 80mm. Photograph Ibolya Feher. 2016.

locality, entanglement (the apparent faster-than-light 'signalling' between widely separated 'entangled' particles) and question the fundamentally probabilistic nature of quantum phenomena. The research in this enquiry pivoted on the findings and the questions they raise and the many themes they uncovered were approached through the exploration of materials more commonly used in a science lab. The practical investigations examined light and optical materials through both the classical and the quantum properties of light, such as reflection and diffraction. Each property contributed to the understanding of the themes entangled within the nature of light.

Applied Textile Thinking

David Bohm engaged many metaphors to describe his thinking. In particular, he used textile metaphors of folding to explain his complex quantum theories of the implicate/explicate order. This inspired a methodology of applied textile thinking. Background research revealed that, in addition to Bohm's metaphors, science uses many other textile terms to describe difficult concepts, such as spinning and entanglement which led to the inclusion of 'Textile Notions' (such as fringes and interlacing) to add insights into the textile language and context.

This research applies textile logic to think about the quantum questions and bring them to physical form in the artworks. The word 'applied' is important here. Applied textile thinking provided a valuable extension beyond the methodological reach of art practice-based research. Together, art practice and textile thinking provide an example of a hybrid methodological strategy, permitting non-linear interconnectedness and offering possibilities for non-linear thought. Rather than solely being used intellectually and metaphorically, the textile tropes are put to practical use in the studio to produce physical artworks, where, most significantly, the multiple elements are simultaneously woven together to reside coherently within the physicality of abstract, mixed-media artworks.

Textile thinking underpins the elements of the whole research and is embedded not only in the text (through the use of metaphors to incorporate and concretise the complex ideas) but also in the artworks and artistic processes. Although it is central, it is difficult to quantify the role played by the applied textile thinking in this enquiry as much of it is implicit. It inhabits the work in several ways; for example, at times there was a conscious intention to apply a textile process to the creation of an artwork, such as physically exploring the notion of folding as a non-linear unifying process. Tim Ingold remarks that, rather than juxtaposing, adjoining or abutting, folding reconciles and unifies (2021:19). Moreover, folding and pleating are ideal actions for transformation, generating novel non-local solutions; for example, ideas of folding were applied to the unlikely realms of light

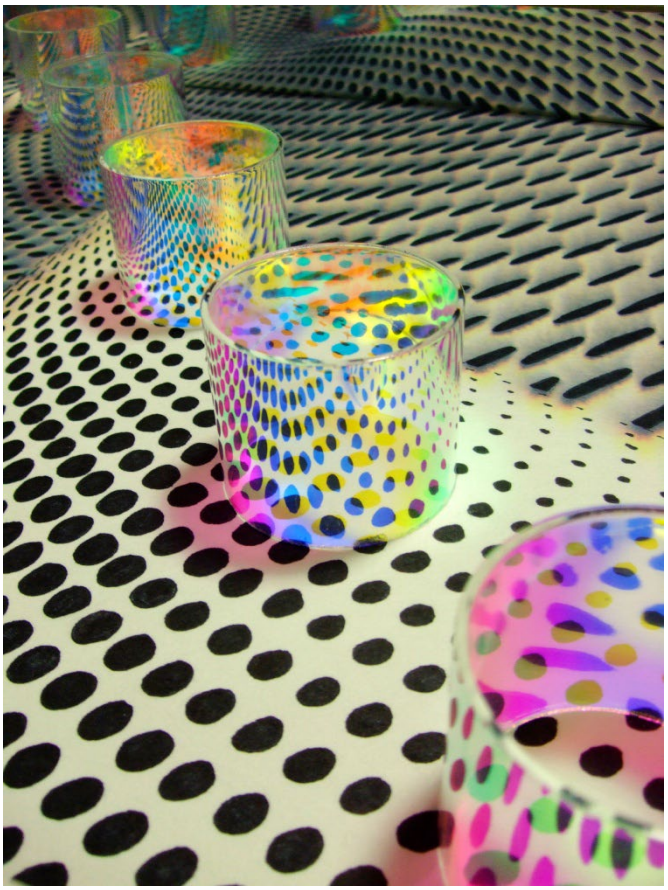


Image 147: *Particles on the Edge of Becoming #7*. Detail view. Shoji paper, dichroic film, black ink, acrylic, mirror, wooden frame. 595mm x 595mm x 80mm. 2017.

and space by using optical materials, such as mirrors and prisms in the *Unfolding Light and Space* series.

Evaluation of the material investigations revealed that subconscious uses of textile processes had entered the work. The use of parallel mirrors not only folded up space in a kaleidoscopic origami fashion, but, conversely also *un*folded perceived space towards infinity. This association with notions of folding became evident only when reflecting on and analysing an artwork after it was made.

Textile methodology is applied to the structure of the thesis itself. The side-by-side presentation of the photo essay and text braid together to contribute to a whole brain experience of two forms of knowledge, lexical and pictorial, towards a fuller understanding of the difficult themes addressed by this research. Beyond this, being inherently non-linear, textile logic can manage multiple complex strands as it braids and folds together the various elements of this enquiry in order to materialise the light-inspired themes through the multiple processes of mixed-media artmaking to allow for an integrated but structured whole.

The approach to textile logic in this study can be useful as an underlying reference frame to researchers in other fields who are interested in interconnectedness, wholeness and nonduality (or unified dualities). It also serves as a model for interdisciplinary research contexts in a way that has not been done before as it interweaves the diverse fields of science, art and philosophy in a non-linear approach. As well as providing conceptual metaphors useful for unravelling thinking about complex subjects, it encompasses thinking through making which incorporates material process exploration with making and meaning, thereby offering a framework for uncovering new insights, ideas and problem-solving methods. It is a model in drawing together the breadth of many different strands as opposed to pursuing a narrow focus in a research project. Additionally, this research contributes to the growing trend to apply textile thinking to disparate fields, such as pedagogical contexts concerning multidisciplinary learning environments and architectural practice in seeking novel solutions (see Chapter 4).

Emergent Themes

Numerous mixed-media artworks, digital animations and installations were founded on the several series of material investigations which aided in the quest to bring the immaterial ideas gained from the enquiry into the nature of light to material form. The understanding gained was used to create artworks that embody and visually supplement the arguments and themes beyond simply illustrating them. These artworks do not simply mirror what we

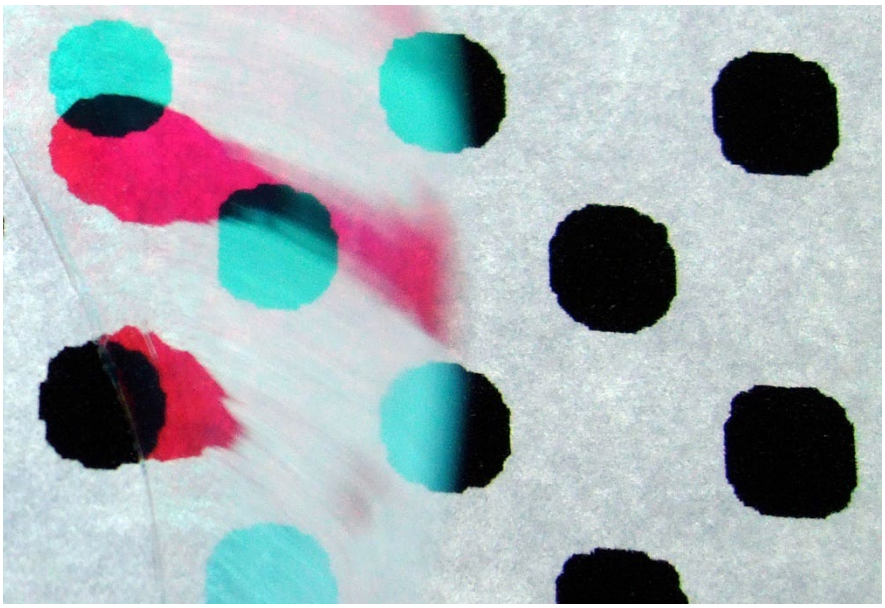


Image 148: Black and white print, dichroic film. 2019.

see; rather, they go beyond mere point-to-point representation to engage the viewer in an active process of perception while revealing something invisible, something that is there but not readily seen. In this research the art functions as an apparatus that reveals something that is usually hidden, for example, unravelling the colours that we know are hidden but don't usually see in the white light that constantly surrounds us. In Paul Klee's first theoretical essay, 'Creative Credo' (written in 1918 and published in 1920), he wrote, "Art does not reproduce the visible but makes visible" (1961:76). He expands on this later in the credo:

> Formerly, artists depicted things that were to be seen on earth, things people liked to see or would have like to have seen. Now the relativity of visible things is made clear, the belief expressed that the visible is only an isolated case taken from the universe and that are more truths unseen than seen (1961:79).

There are many interpretations of the bizarre results of the two-slit experiments and this research was inspired by the theories of two physicists. Firstly, Niels Bohr's Copenhagen interpretation which proposed the notion of complementarity. Complementarity dominated Bohr's thinking in both science and philosophy and provides for the difference between organic and inorganic matter and could underlie other classic dualisms like subject/object, mind/body, reason/passion and free will/deterministic causality (Wilkins 1987:338-360).

One device used in this research is based on unifying dualities through use of unified complementary colours. This is used in two ways; firstly, the positive/negative interlaced images of the lenticular prints and secondly, with novel uses of dichroic film which points to quantum entanglement. These uses of dichroic film disrupt normal expectations of transparency and reflection. For example, when the film is manipulated to create cylindrical forms, there is a dance of complementary coloured reflections of black ink drawings in the curvature of the film. The shifting colours exist as entangled complementary pairs, expressing the simultaneity of quantum entanglement.

The second key interpretation is from David Bohm whose unorthodox theories are extensive. Theories of the implicate/explicate orders propose that the apparently separate aspects of the phenomenal world originate from an underlying wholeness of an order of non-local interconnectedness, "the universal flux", which is a state where everything is in a process of becoming and can only be known implicitly (1980). Many of the artworks in this enquiry pay homage to Bohm's theories through their motifs, compositions and even directly through their titles.

Deriving from Bohr's interpretation, Karen Barad proposed theories of intra-action and agential realism and developed a 'diffractive methodology'. Diffraction is non-linear and

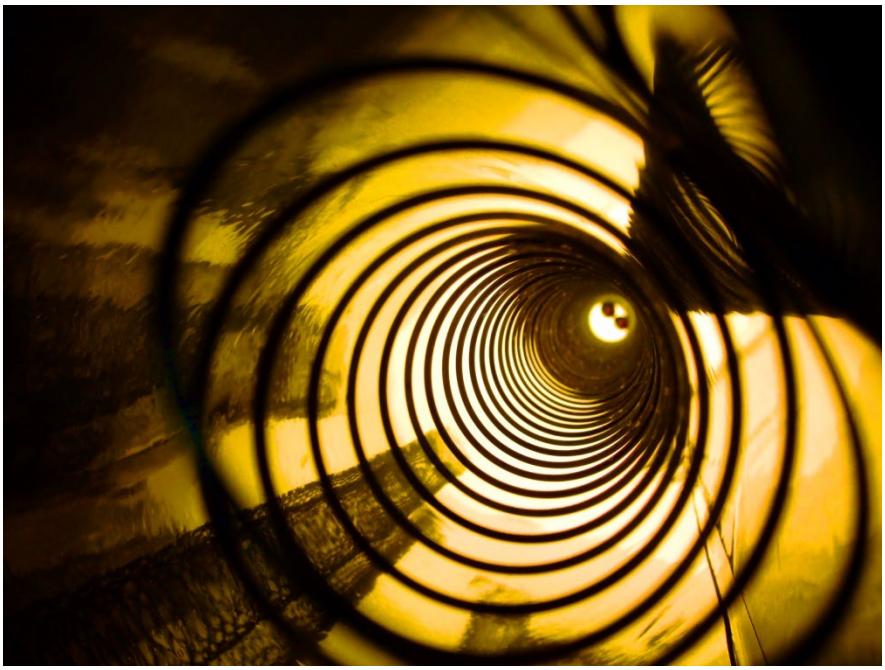


Image 149: Two-way mirror film, coiled spring, sunlight. 2016.

disrupts the usual point-to-point correspondence of a reflection (Barad 2007:86-94; 2009) and is a key theme in this research. Materially interrogating diffraction grating produced several optical effects that visually and experientially suggest quantum properties, such as superposition and questions of boundary.

Original uses of diffraction grating present new ways of understanding and experiencing the shifting and paradoxical nature of quantum states that underlie light and matter, such as superposition by questioning boundary and indeterminate positions in space. When placed over pleated, printed, transparent acetate, diffraction grating creates shifting, rainbow-hued duplicates of the black images on the folded acetate. These multiple, hovering, ephemeral colours appear to exist in layers and their exact location cannot be determined. The coloured shapes lose their singularity and blend into one another in dynamic overlapping patterns which constantly alter as the viewer moves. One cannot distinguish and focus on a single element in the image because its edge is diffuse and constantly shifting. It is not possible to see where each image ends and another begins as each overlays the other and appears to be in more than one place at once—in superposition.

The themes that emerged from the interrogation of light included wholeness, unifying dualities and questioning boundaries. Wholeness is key to the hidden, immaterial aspects of our reality and emphasises the underlying oneness and interconnectedness of all things. Physicist Arthur Zajonc stated, "At the level of the quantum, light is whole" and, he added, "The mysteries of quantum mechanics, its paradoxes, wake us up to the deepest aspects of our world" (2015:120). Wholeness is implicit in the scientific viewpoints outlined earlier in the text—in Einstein's Relativity, quantum mechanics and Bohm's theories of interconnected wholeness. Paradoxically, we know more of the nature of whole by looking at the parts. Wave/particle duality points to this wholeness and was another quantum question incorporated into the artworks. Questioning dualities more broadly was a key aim of the research and included bridging opposites, such as positive/negative, interior/exterior, subject/object and materiality/ immateriality.

The scope of the themes was far-ranging, making defining the limit of the enquiry problematic. What was required was a way to frame the project to fit the conventional expectations of doctoral research which requires both naming and framing. Perceived boundaries separate and the question of boundary is another of the key quantum questions. Interrogations of boundaries recur throughout the project exposing the indeterminate interfaces and interconnectedness between things. The solution came through thinking-by-making of the *Indeterminate Interface* series which led to an understanding of permeable boundaries that could permit multiplicity. The dual nature of

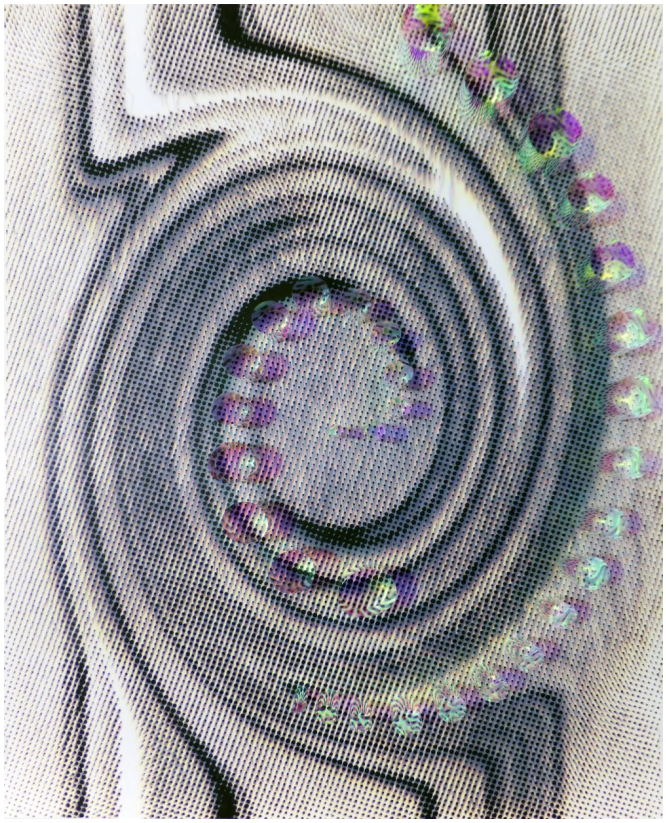


Image 150: *Holomovement, #1*. Shoji paper, dichroic film, black ink, mirror, wooden frame. 1205mm x 940mm x 80mm. 2017.

the physical framing of the works (the fading edges of the play of light on the walls and the crisp edges of the prism blocks) presented the answer to this dilemma and served as a concrete model for framing the project as a whole. The *Intermediate Interface* series pointed to the possibilities of defying limits but without denying boundary. This is a visual/experiential contribution to an inclusive both/and mode of thought where opposites or things with opposing properties can coherently co-exist.

In addition to the marriage of art and quantum ideas, the incorporation and visualisation of Bohm's theories in particular will be useful to the growing number of organisations that transverse the physical sciences, life sciences, social sciences, spiritual traditions and the arts, concerned with wholeness and interconnectedness, many of whom are already interested in and value Bohm's philosophical and scientific ideas. I presented some of the findings of this research directly inspired by David Bohm during the David Bohm Centennial Celebration to celebrate the life and work of David Bohm in September 2017 at the Pari Center, Pari, Italy. A paper 'Frozen Light: An Artist's Response to David Bohm's Theories' (Jacobs 2020b:207-210) was published in the *Memoriam David Bohm 1917-1992* edition of Pari Perspectives journal and I contributed an online presentation, 'Unfolding Colourful Secrets Tightly Enfolded in White Light' for *Online Pari Community Conversations: Science, Art and David Bohm* (Jacobs 2020a).

Art Practice

Art practice is the primary site of the research and it provides a model for cognitive alternatives to intellectual thought (both conscious and unconscious thinking) through looking, doing and making. The artworks contribute to knowledge through visual and experiential languages, moreover, they are also the primary vehicles for transmitting the discoveries to others. Their creation was founded on the sustained focus on the study's themes (such as unifying dualities and the entangled relationship between subject and object). Using a quasi-scientific approach, repeated sampling enabled an in-depth interrogation of the (often illusory) optical qualities of specific materials in several series of material investigations. Many of the materials are typically used as beam-splitters by physicists in the two-slit experiments, notably prisms, mirrors, dichroic materials and diffraction grating. Close examination of the materials revealed surprising and illusory results which enabled them to be used in unconventional ways, giving rise to novel and unusual forms.

Paradoxically, the physical natures of the materials' relationship with light pointed to the immaterial themes arising from the notion of the edges of becoming. This approach of using materials to effectively express immateriality had been confirmed through seeing the

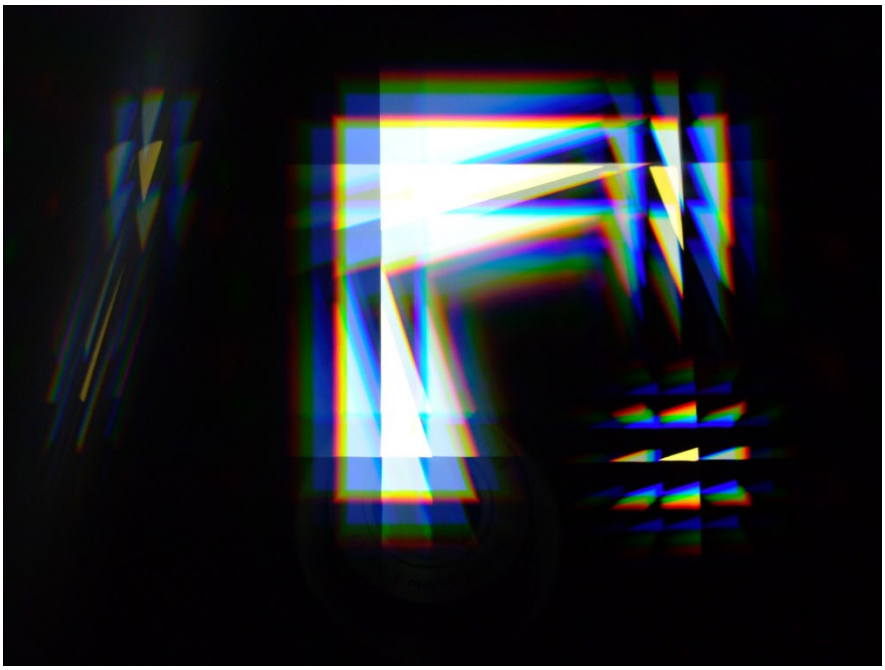


Image 151: Cut black paper, Diffraction grating, LED light. 2015.

art of Eastern artists during a research trip to Japan and South Korea where many of these artists deliberately used materials to tangibly express, portray and advance understanding of immaterial phenomena such as infinity.

The materials embody and visually supplement the themes beyond simple illustration, they experientially convey the themes to non-academic audiences as both their compositions and novelty focus and direct the viewers' attention. The processes of the RAS allow the viewers to form their own perceptual links, so that the works are a site for making and remaking perceptions of the world by challenging prior fixed beliefs, viewpoints and assumptions based on a mechanistic and fragmented worldview at a subliminal level. Thus, they enable a shift in perception towards ideas of wholeness, interconnectedness and unification of opposites, potentially leading to breakthroughs in perception. The art makes the themes accessible to others through a visual language that directly affects perception, thereby becoming a source for fresh thinking that offers the potential for viewers to shift fixed beliefs.

How understanding of these materials was used in the artworks were discussed. For example, the qualities of the internal reflections of prisms not only set up illusory reflections that give the appearance that there are more objects (such as gold dots) than there are in reality, suggesting that things are not what they seem. This property of prisms also leads to the possibility of hiding elements within the artworks which are then only visible from certain viewpoints. These elements emerge or disappear depending on the viewers' position and point to a hidden order that exists beyond all things. As elements are both there and not there, they create uncertain and shifting experiences of reality commensurate with quantum properties.

Exploiting and developing the usually unwanted moiré effects of lenticular photographs led to creating static lenticular works that dynamically and kinetically articulate Bohm's holomovement (the process where the undivided wholeness of the implicate order underlying reality is in a perpetual process of flux and becoming. These moiré effects also question a fixed position once again.

The results of the many material investigations were often characterised by contradictions which were useful in informing the problematic and paradoxical ideas, and bring them to form. By working and reworking the themes and motifs, these ideas are repeatedly presented in different ways across the body of work, each variation offering a different angle on the themes and contributing to further developments in the explorations and expression of the ideas. The materials offered different degrees of success in expressing,

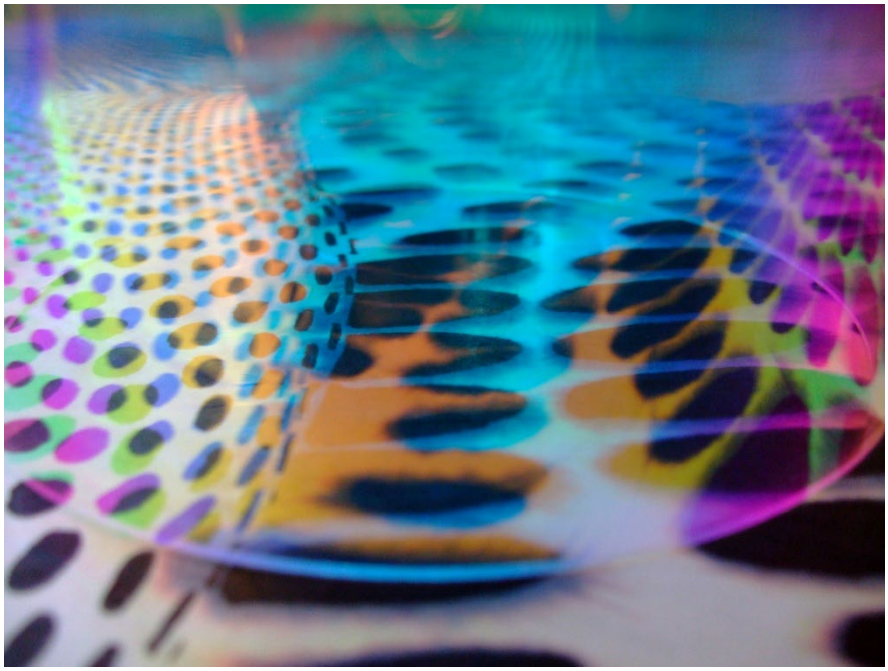


Image 152: Quantum Questions—Unfolding Implicate Order #2. Detail view. Shoji paper, dichroic film, black ink, mirror, wooden frame. 940mm x 940mm x 80mm. 2018.

illuminating and demonstrating the different quantum themes. They could be combined with each other in the artworks. A summary of the findings follows.

Diffraction Grating

The use of appropriated laboratory apparatus used as beam splitters, diffraction grating, dichroic materials, prisms, and half-silvered mirror afforded the representation and expression of quantum properties that lead to expressing the philosophical themes that emerged, such as, nonduality, superposition, entanglement, indeterminate boundaries, wholeness and interconnectedness. As well as untangling and revealing the coloured spectrum entwined in white light, diffraction grating was the most successful material in being more than a representation of superposition (a particle being in two places at once). It gives an *experience* of superposition, pointing to a hidden underlying wholeness. For example, in the *Unfoldings—Implicate/Explicate I* (see Image 133) the light is diffracted around black printed dots, generating shifting and morphing echoes of the marks into patterns of soft rainbow hues. As quantum physicist, Arthur Zajonc observes, "One photon can be the superposition of many colours. Even in its least part, at the level of the quantum, light is whole" (2015:120). The diffracted particles are on the edges of becoming, appearing and disappearing, shifting and morphing as the viewer moves position.

Dichroic Materials

Karen Barad observes that diffraction is itself an entangled phenomenon (2007:73), likewise the dual nature of dichroic film offers an experience of quantum entanglement. Entanglement is the apparent faster-than-light 'signalling' between widely separated 'entangled' particles, where the direction of spin in one particle simultaneously switches as the spin in the other is changed—entangled particles must have opposite spins. The colours seen through dichroic film have the opposite colour in the reflections in the film and provide an experience of quantum entanglement as each colour in the film and the reflection both always switch to their opposite (complementary) colour simultaneously. In addition to demonstrating entanglement, this also presents an experience of unified duality. Artworks employing dichroic film in this way include, *Quantum Questions—Unfolding Implicate Order #2* (see Image 152) and *Unfolding Light and Space: Study I*, (see Image 143) and the *Quantum Questions—Line Interrupted* series (see Image 76).

Image 153: Lenticular photograph. 2021.

Half-Silvered Mirror

Due to the properties of the half-silvered mirror in the small vitrines of the *Unfolding Light and Space* series and the immersive *Beyond Dualities Pavilion,* Fixed point perspectives are disrupted and one experiences a dual play of transparency and reflection. The experience is paradoxical and challenges the viewers' perception of dualities, both polar opposites co-exist in several ways, the contained spaces are both small and infinite simultaneously. Also, there is an interplay between what is real and what is virtual (reflected) and the mirror is both transparent and opaque, disrupting expectations of how mirror usually behaves. The objects inside the small mirror boxes are both singular and multiplied at the same time, the viewer inside the pavilion also experiences this duality as they see themselves duplicated over and over into the distance.

The use of this mirror interprets and synthesises and represents Bohm's theories of the unfolding and enfolding of the explicate/implicate orders. Inspired by Bohm's use of these textile metaphors, the notion of folding is brought to the realms of light and space—an original application for mirrors.

Lenticular Prints—Unifying Dualities and the Holomovement

Another opportunity to express Bohm's theories are during the material investigation of lenticular printing which as initially used for its potential to explore and present the theme of bridging dualities and exploring quantum notions of particles and anti-particle. Lenticular photography folds together two or more images concurrently by interlacing dual versions of an image (a positive and its negative). Lenticular prints are a device for unifying dualities as they change from an image and its inverse as the viewer moves—both opposite images are contained in the same space

Exploiting and developing the usually unwanted moiré effects when creating lenticular photographs, introduce moiréd vortexes—an original way or using lenticular prints. They dynamically and kinetically articulate Bohm's holomovement (the process where the undivided wholeness of the implicate order underlying reality is in a perpetual process of flux and becoming. Depending on the viewer's direction of movement, to the left or to the right, the moiré waves of the vortex pulse in and out, centrifugally or centripetally around a central point of an image that references particles, the colours flipping to their inverse in the process. This is an expression and experience of particle/wave duality. The waves are solely an optical effect and do not actually exist in the printed ink.

Bohm maintained that reality is in dynamic process, however, thoughts and beliefs structures tend to make things appear to be static and fixed. In his book, *Unfolding*

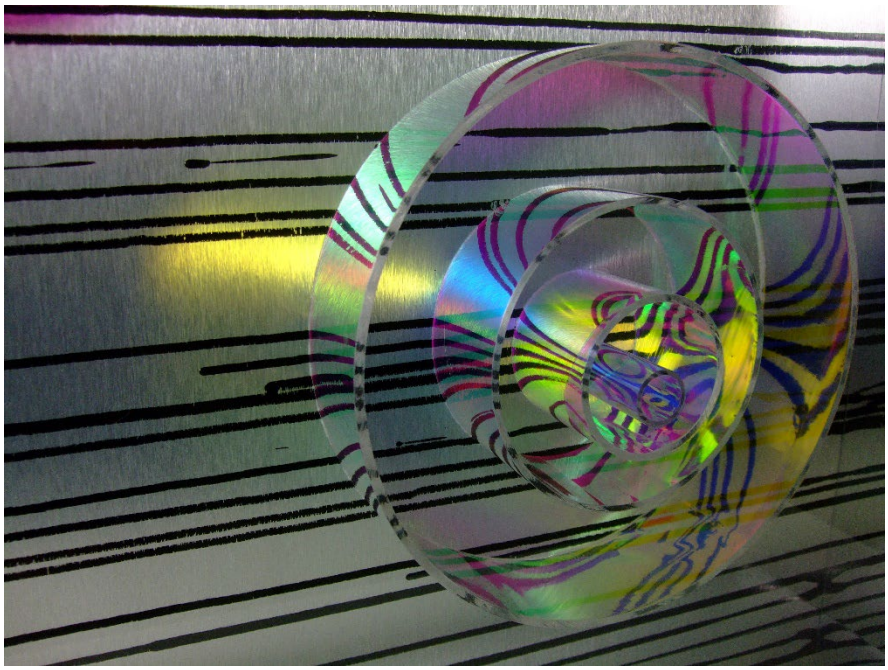


Image 154: From *Line Interrupted* series. Black ink drawing on brushed aluminium substrate, dichroic film, acrylic tube. 2016.

Meaning, Bohm suggests a softer approach, "The challenge is to dissolve this old pattern of thought and perception rather than to try to contradict it, to control it, or to destroy it by force, or by will" (1985b:153). This supports the aim of the artworks for this inquiry to question the fixedness of positions by offering multiple visual experiences simultaneously. Each viewpoint bears equal validity even though it is unlike another view. Most of the artworks invite the viewer to move position to see alternate views, in particular, the all works that include the optical materials: diffraction grating, dichroic film, mirrors and prisms, such as, the immersive *Beyond Dualities Pavilion,* the small *Beyond Duality* series, the *Unfolding Light and Space* series and the *Quantum Questions—Line Interrupted* series.

The Observer Effect

The 'observer effect' is key to quantum physics, Niels Bohr's argues that there is no definite way to distinguish between the observer and the object—in the two-slit experiments, the outcome depends on whether or not the experimenters are detecting which of the two slits the photon or electron passes through or not. Barad summarised that these experiments demonstrate that the experimenter/apparatus, subject/object are thoroughly entangled (2007:14). Correspondingly, the actions of the viewers are crucial to the experience of artworks and installations, such as the *Quantum Questions—Line Interrupted* series and the Lenticular series. They activate the work by receiving different visual information from different angles of the artwork as they move position. The artworks are activated and changed in surprising ways as the viewer moves, thereby they experientially question a fixed position.

The results of the investigations were collated into a photographic data record that provides a non-verbal contribution to knowledge, extending the range of aggregated information to create an overarching oeuvre that holds and represents the themes identified in this research. Many of these photographs constitute the photo essay accompanying this text and are also incorporated into the projected images in the large 'particle' installation in the final exhibition.

The non-linear and evocative nature of the visual information in the companion photo essay provides the reader with the opportunity for free association and allows them to make their own individual links and inferences. The images in the essay visually support and extend the themes embedded in the text, providing an additional form of information (independent from but related to the written words). Together, the text and the photo essay offer a dual experience of the subject matter. The two threads of different forms of

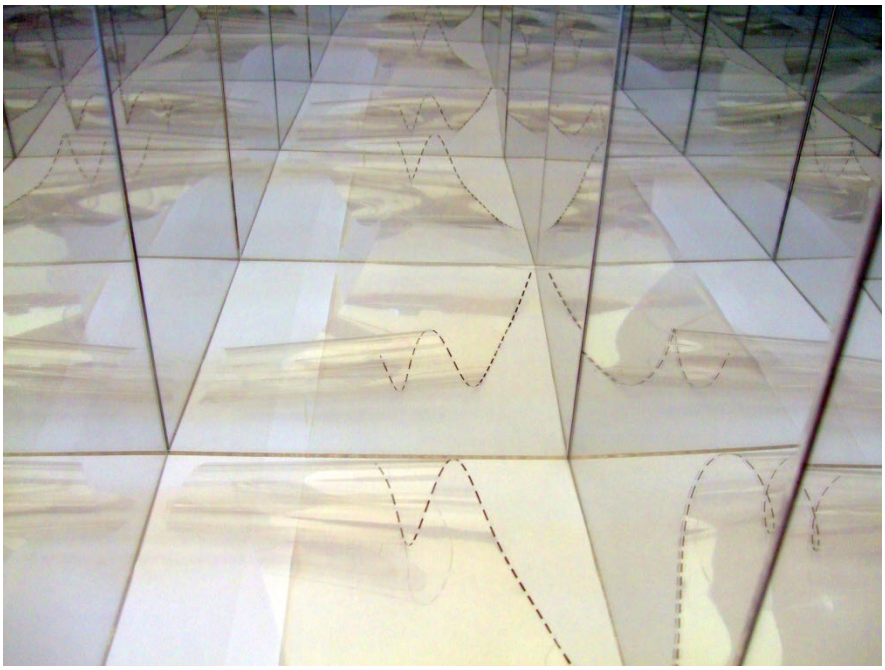


Image 155: Mirror, printed acetate. 2018.

information presented side-by-side promote a wider comprehension in the reader, who becomes both a reader and a viewer simultaneously—both/and. The photo essay is an intermediary between the thesis and the studio practice, forming a third means of disseminating the information and discoveries gathered in this research.

The material investigations led to discoveries in how to use the art processes (which are complex and entangled) to evolve the ideas. Each medium used in this research required its own approach in working and re-working the themes and motifs. In Chapter 9, this was demonstrated through discussion of the developments of several Lenticular series which were treated as a case study to demonstrate the complex and entangled evolution of the artistic processes. Outcomes were driven by aiming to bring the scientific theories and philosophical themes into form and the process was initially used as a way of thinking about wave/particles and other dualities.

Beyond this, the physical and optical qualities of lenticular photography were interrogated and ways of accentuating the moiré effects were developed. The technical possibilities of lenticular production were pushed beyond the usual limits of the process which generated novel outcomes that contributed not only to illuminating and expressing the themes of unifying dualities, but also to visually presenting the dynamics of David Bohm's *holomovement* in a dynamic form as described earlier.

Overall, the artworks offer a gestalt, a syncretic understanding beyond language and they impart their implicit knowledge through the non-verbal language of art. Architect, Juhani Pallasmaa, understands this well; he writes, "Perception, memory and imagination are in constant interaction…When experiencing a work of art, a curious exchange takes place; the work projects its aura, and we project our emotions and precepts on the work" (Pallasmaa 2005:67-68).

The artworks and art practice serve as an inspiration not only to other creatives but also to scientists. For example, several of the artworks hang in the common spaces of Science Creates's St. Phillips premises in Bristol where they are much appreciated by the scientists who recognise the illumination of the entangled quantum themes that the works incorporate. Many are also familiar with Bohm's theories and verify that the themes are well presented. Artists and designers can benefit from and employ the approach to both the material investigations and the discoveries of how the appropriated apparatuses (including prisms, mirror, half-silvered mirror, dichroic materials and diffraction grating film can be artistically used to aesthetic advantage).

Image 156: Installation view Quantum Light—Beyond a Crisis of Perception exhibition. 2022. Photograph Kim Spanoghe.

Discursive/Immersive Exhibition

Because the viewer completes the works, the most effective way for a person to experience the ideas that the works express is to be in the presence of the works themselves—where the themes can be seen, felt, experienced and perceived by others. The compositions of the artworks focus and direct the viewers' attention and they also present novel and puzzling experiences. Their novelty is key because, as was described in the introduction to this document, the RAS attends to what is novel. Perception is not fixed but is an active process. The RAS constantly updates the database in our brains to inform our current perception—a cycle where our experiences, especially novel experiences, form the basis of our future perception (Seth 2018). The RAS allows the viewer/reader to form their own perceptual links.

The final exhibition, serves as a conclusion to this research. It presents a selection of the artworks made during this enquiry that convey the content of the research to both academic and non-academic audiences in two different ways—discursive and immersive (discussed in Chapter 10). The exhibition is in two parts separated by the *Double Aperture Moiré Wall* (see Chapter 10) which is a large fabric-covered wall with two narrow openings that divides the gallery. The first part is mainly discursive with framed artworks, caption labels and wall text which engage the viewer cognitively through looking. A range of resolved works and images from the material investigation are shown, and together, they give a multi-faceted view of many of the themes, threads and motifs.

Double Aperture Moiré Wall, Quantum Breath and *Particle Paradox* combine into one installation that offers a whole-body sensory experience of the two-slit experiment, referencing particles and waves and moiré interference patterns. Together with the *Beyond Duality Pavilion,* these immersive installations form a second multi-sensory mode of encounter which elicits a bodily response from the viewer. Simon O'Sullivan (2005:1) says that an art encounter (as opposed to "an object of recognition") challenges our accustomed ways of being and disrupts our knowledge systems and we are forced to think. *Beyond Duality Pavilion* (see Chapter 10) is a two-way mirrored walk-through cabin. When people enter the structure, the small space appears to open out towards infinity and they see reflections of themselves multiplied in two directions. They experience the vortex artwork in the ceiling repeatedly reflected in the mirrored walls and floor below them stretching out like a patchwork quilt. Curiously, the colours of the circular shapes within the images of the vortex change from magenta through to orange, yellow and green as the reflections recede into the distance.

Image 157: Two-way mirror, dichroic film, wire, LED light. 2015.

Loose Threads—Suggestions for Further Study

As the enquiry progressed, many possibilities for further research opened up. There are many threads that could be picked up, drawn together and worked into further research. There is scope for finding more ways of presenting bridging dualities or the union of opposites. For example, one could take the observations gathered together in the essay, 'Complementarity and the union of opposites' by Nobel laureate, Maurice Wilkins as a starting point. This would include seeking a fuller understanding of notions of wholeness and dualities based on Carl Jung's theories on wholeness and opposites (dualities), and the coincidence of opposites (*coincidentia oppositorum*) is one of the fundamental organising principles in his thought. Jung was influenced by Taoist thinking and wrote the commentary to a Chinese book of life, *The Secret of the Golden Flower,* (translated by Richard Wilhelm). Significantly, Jung felt that the only solution to conflict is the union of opposites (1941/1959:168).

In a project with a broad scope, such as this, what is covered is a matter of focus—there are inevitably loose ends that might have been covered had the focus been different: location of focus changes what comes into view. One could pull on any one of these loose threads to unravel a whole new area of research. Many of these possibilities are beyond the scope of this project and include other scientific theories, such as chaos theory, deeper forays into the philosophical questions, further investigations of the optical materials and following threads emerging from hitherto, yet-to-be-made artworks. For example, there is scope for further investigation into the interference patterns that led to the exploration of moiré, an interference phenomenon commonly seen in layered gratings and textiles, such as net curtains.

Following the scientific threads could include exploring many other interpretations of the two-slit experiments, for example, unravelling the textile metaphors used in string theory and multi-string theory (M theory). Hugh Everett's Many Worlds Interpretation holds that there are many worlds which exist in parallel in the same space. This could lead to further developing the artworks made using parallel mirrors such as the *Beyond Duality Pavilion* installation and the *Unfolding Light and Space* series. Yakir Aharonov's time-symmetric interpretation, where the double-slit experiment gets information from the future, could initiate an exploration of time.

Bohm's wider theories on dialogue and creativity also offer the foundation for opportunities for further research. Moreover, Bohm's theories also have significant implications for the understanding of the relationship between mind and matter and consciousness. The Pribram-Bohm Holoflux Theory of Consciousness is drawn from the holonomic mind/brain

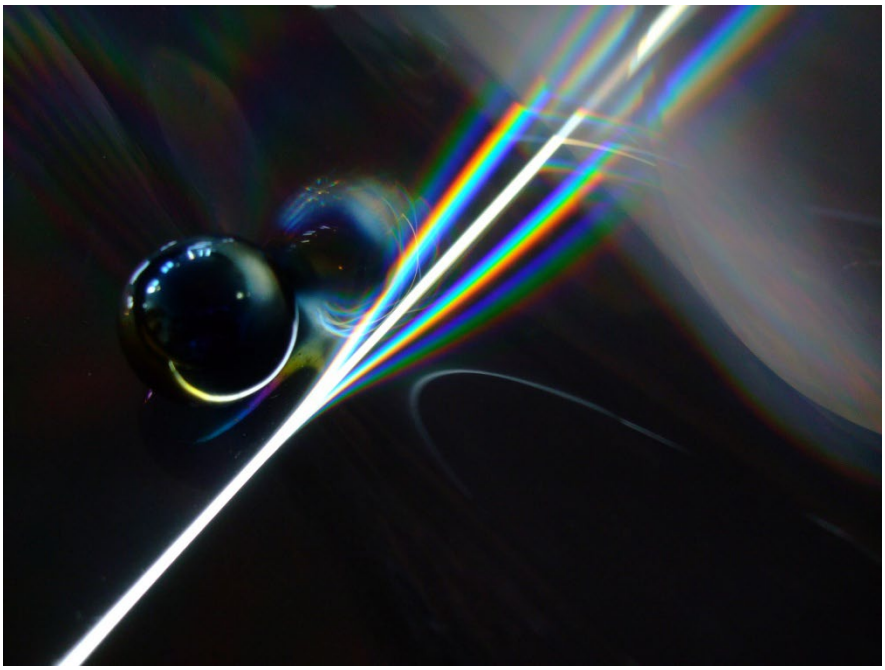


Image 158: Black paper cut with one slit, black marble, LED light. 2016.

theories of Karl Pribram and Bohm's holoflux theories which conform to principles of physics, mathematics and electrical engineering (Joye 2016:114-136).

Bohm says of mind, matter and light,

> The mind may have a structure similar to the universe and in the underlying movement we call empty space there is actually a tremendous energy, a movement. The particular forms which appear in the mind may be analogous to the particles, and getting to the ground of the mind might be felt as light. The essential point is not that it's light but rather this free, penetrating movement of the whole (cited in Weber 1986:48-49).

In *Mind, Matter and the Implicate Order*, Paavo Pylkkänen clearly and thoroughly analysed and extended Bohm's theories, building his view of the cosmos as an enfolding and unfolding whole. Pylkkänen acknowledges that Bohm not only offered a new proposal about the fundamental architecture of matter with his theories, but that he also made proposals for the nature of mind and its relationship to matter (2010:12). Using yet another textile metaphor, Bohm said the following of matter and consciousness:

> They're interwoven. They're correlative categories of reality, always woven together just as form and content are woven together. Every content is a form and every form is at the same time a content. Another way of saying that is that everything material is also mental and everything mental is also material, but there are many more infinitely subtle levels of matter than we are aware of (1986c:151).

The relationship between the phenomenon of light and the human experience of the inner light of spirit encompassing religion, eastern mysticism, poetry and mythology is another rich and extensive area for further enquiry.

Loose ends are not ends but are in effect really beginnings…

The Whole Cloth

Drawn from an understanding of the nature of light, this research seeks to highlight and illuminate the wholeness and interconnectedness underlying the world we perceive. It has been reassuring to be investigating the nature of light and the lessons and insights it brings to counterbalance these dark times. World events have highlighted the complexities of global interrelation and substantiated the need for seeking holistic solutions rooted in an understanding of interconnectedness. Physicist Fritjof Capra observed the global issues that result from a crisis of perception stemming from a reliance on thinking primarily governed by reason and individualism and a dualistic, binary, either/or position (1996, 2014:xi; 2014:363). He argued that finding solutions by navigating the problems differently requires a perceptual shift that can dissolve old patterns of

Image 159: *Indeterminate Interfaces.* Installation view Quantum Light—Beyond a Crisis of Perception exhibition. 2022. Photo:Amak Mahmoodian.

thought in ways that can reconcile opposites and reunite the splits between body and mind, science and spirit, reason and intuition (1985b:150-153), us and them.

Identifying a need to evolve from 'a crisis of perception' based on dualistic thinking and fragmentation to a breakthrough in perception based on wholeness led to creating artworks that can contribute to a transformative shift in perception towards a holistic worldview. This is based on the assumption that, by receiving information directly through the senses, viewing and experiencing artworks cause shifts in perception in the brain's RAS. Although the artworks do not specifically address or engage with any global problems directly, they visually and experientially present quantum properties such as superposition and entanglement, questioning boundaries, reconciling dualisms and loosening fixed beliefs and viewpoints based on a mechanistic and fragmented worldview. Holistic perspectives can overcome dualistic thinking and can point us towards a fresh way of forging solutions— of "both both/and *and* either/or" (Ascott 2005). In this way they become sites for transformation.

The aim of creating the artworks for this research was not to produce absolute answers or present conclusions, but to open a space where questions as to whether our current perception of reality is all that there is could arise. It seeks to interrogate the recurring themes that have the potential to change perception and perspectives and bring them to material form through visual articulation. They appreciate the potentiality of uncertainty and raise questions rather than providing absolute truths. These works present an experience that overcomes binary oppositions without relinquishing the characteristics or qualities of each, thereby containing and holding contradiction and duality and offering possibilities for shifts in thinking beyond dualistic polarisation. Complex interconnected relationships between subject and object are exposed and the boundaries and interfaces between things are questioned and alternative perspectives are offered. Disruption of fixed perspectives and fixed viewpoints experientially and visually demonstrates that there is not only one solution/valid way of perceiving the world.

Coming from a standpoint that everything is interconnected, these works repeatedly challenge the belief that we are separate. Our sense of separateness is an illusion; we are not isolated individuals and cannot step outside the whole. Curiously, the very illusory nature of optical materials and compositions of the artworks express unity and interconnectedness: Goethe said, "Optical illusion is optical truth!" (cited in Zajonc 1995:194; 2015:120). Through illusion, the artworks expose and illuminate the difficult and paradoxical world of quantum light and the questions it raises, presenting them in

Image 160: Black ink lines on silver substrate, dichroic film, sunlight. 2018.

concrete forms that confound ordinary perception. They make things that cannot be perceived perceptible.

There are no definitive answers to the hard questions undertaken in this enquiry; however, it seeks to offer further contributions towards understanding them. The themes are timeless and many others have sought for a universal key. Just as physicists have been chasing a 'theory of everything' for the last century, this field of study is, by its nature, incomplete and is likely to remain incomplete. Due to the mysterious nature of the subject of enquiry, there will always inevitably be gaps in our collective understanding. Notwithstanding, it is through an inclusive, syncretic, non-linear and braided approach, drawn from textile thinking and spanning disciplines, that this research illuminates and draws links between modes of understandings. It highlights correspondences between several worldviews that are concerned with the nature of light, and each perspective provides illuminating facets that serve the whole and contribute to an interwoven (but open) body of knowledge.

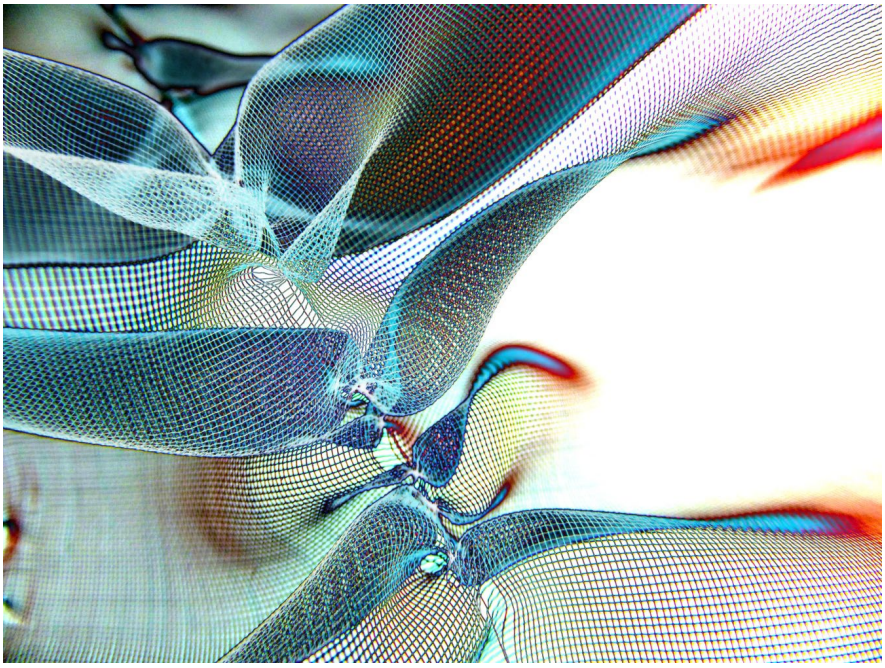
Just as Systems Thinking recognises that all scientific concepts and theories are limited and approximate—science can never provide a complete and definitive understanding—the conclusions of this research remain open (Capra & Luisi 2014:82). Nonetheless, as Capra and Luisi observe, although approximate models and theories to describe the "endless web of interconnected phenomena" are inherently incomplete, they are, nevertheless, effective and can be developed over time (2014:82).

Michel Serres uses several textile metaphors throughout his texts. Here, he questions issues in the world situation:

> The state of things has become tangled, mingled like thread, a long cable, a skein. Connections are not always unravelled. Who will unravel this mess?...The state of things is creased, crumpled, folded, with flounces and panels, fringes, stitches and lacing" (Serres 2005:82).

The textile thinking applied to the complexities of this research, exemplifies the potential for textile thinking to be an effective way of working through many varied situations in a non-linear, reconciliatory and unified way.

In this enquiry, textile thinking provided a valuable overarching methodological framework of 'soft logic' (Serres 2015:197). Pennina Barnett and Claire Pajaczkowska (2007) define textile thinking as "an inclusive mode of thought that weaves, ties and holds things together that makes connections". The properties of textile logic reconcile and unify (rather than juxtapose) disparate elements and apparent polar opposites—soft logic is



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"continuously changing and forming itself, acquiring a new shape and rediscovering itself in every encounter" (Taragan 2014). As well as offering possibilities for non-linear thought, textile thinking provided a framework for a mixed-media approach to making artwork and generated non-local solutions in the material investigations.

The metaphor of a whole cloth woven from many threads is appropriate to this enquiry. This definition aligns with the intention of this research—to seek wholeness and produce coherent visual forms expressing complex abstract ideas, making connections and relationships and seeking to highlight correspondences across genres.

*

The question remains however—*are s*pace, time and material one with light? There is no definitive answer. This question is an invitation for a lifetime's exploration and study into the rich and penetrative nature of light, contributing to understanding the fabric of space/time—the edges of becoming.

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All works created by Peta Jacobs. © Peta Jacobs 2022.

Unless otherwise stated, all illustrations in this list were photographed by Peta Jacobs.

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