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Editorial: "The Old One does not play at dice"

Robert Marks

Economics, University of New South Wales, Sydney

E-mail: robert.marks@gmail.com

This issue contains three submissions — papers by Rendsburg, Holman, and Anemaat — on, respectively, a Hebrew fragment found in an old book in the Fisher Library at Sydney University and how it was identified, the science of red meat in NSW, and surviving drawings made during the first days of the Colony at Botany Bay. As I have remarked before, the *Journal* is not the first choice for young academics, and so I look for possible submissions from older contributors. In this issue there are two commissioned papers: a long one by John Spence FRS on the history of measuring the speed of light and where that led to in 1905 and later, and a shorter one by Rob Burford FRSN on the history of plastics (aka polymers) over the past century or so. There is a paper by Barbara Gillam FRSN, reprinted from the journal *Leonardo*, where it is not very accessible. We hope that its appearance here results in greater exposure. There are five PhD abstracts, including one (by Tran) that should have appeared in the print version of the June issue, but did not. Finally, there is an obituary of Ann Moyal FRSN (1926–2019), who was the first recipient of the Royal Society's History and Philosophy of Science Medal in 2014. She was also a co-author of mine. I am grateful to Stuart Macintyre AO, a former Dean of the Faculty of Arts at the University of Melbourne, for agreeing to write the obituary.

David Attenborough tells us[1] that when he was a schoolboy in the 1930s, his science master showed them a marvellous new substance that had been invented, called plastic. It was light, it was cheap, and it could be used for a multitude of things. In centuries to come, the teacher said, people would look back in the twentieth century and say that was the plastic period! That was, Attenborough says, truer than the teacher knew, because, yes, it had all those advantages, but the mere fact that it was indestructible meant that it could not be thrown away. Plastics manufacturers advised that once it was used it should be thrown away. But there is no "away:" plastic is so permanent that it does not decay or rot. Hence our growing problem with plastic waste, on land and in the oceans. Although his paper focuses on the advances in polymer chemistry that have resulted in new plastics, Burford does make some suggestions about this issue, through changes in our behaviour and in new chemistry.

My old friend John Spence has recently published a book (2019) on the history of measuring the speed of light, and the consequences for our understanding of the Universe that ensued, over a hundred years ago, including Einstein's 1905 paper, and also indirectly to quantum physics. At my request, he has written a paper that summarises his book, published here. As Spence

[1] A message from naturalist Sir David Attenborough: Plastic Oceans, OceanVistaFilms, https://www.youtube.com/watch?v=cX1T79ZKJqM

recounts, in 1900, despite the achievements of Newton and Maxwell and many others, there were two puzzles in physics: the failure of the Michelson-Morley experiment and the black-body radiation problem. Solution of the first puzzle led to special relativity, and solution of the second led to quantum theory, with all its weirdness.

I recently came across a fascinating "life" of the Italian polymath, Jerome Cardano (1501–1576), who has variously been described as a gambler and blasphemer, inventor and chancer, astrologer and astronomer.[2] In notes he wrote in 1520 while still a student, much later posthumously published as a book, he was the first to attempt to derive a law of probability applied when a die is cast, as formulated in Cardano's Formula. This was over a hundred years before Leibnitz in 1676, and over two hundred years before Laplace's foundation of probability theory in 1774. As a gambler, Cardano was motivated to understand this to win at dice. As an inventor he invented the forerunner of the Cardon universal joint which facilitates the transmission of torque between two shafts positioned at various angles. And, in his pioneering work at solving cubic equations, he derived numbers that were multiples of the square root of minus one, at a time when even negative numbers were suspect.[3] He thought such entities (imaginary numbers) were useless rubbish. It's surprising to realise that the two basic ingredients of modern quantum theory, namely probability and complex numbers, were discovered by one man, four hundred years before quantum theory itself was developed.

Ekert (2008) asks whether we have to use Cardano's discoveries (probability and complex numbers) to describe the world. Predictive determinism is the view that, if at any time we knew the positions and velocities of all the particles in the universe, then, at least in principle, we could calculate their behaviour at any other time, past or future. This was the official dogma until quantum theory was developed a hundred years ago, which rules out sharp predictions of measurement outcomes. Instead, we must use probabilities. Moreover, causal determinism, in which every event is caused by, and hence determined by, previous events, does not always hold in a quantum world. After some discussion of the connection between complex numbers and probabilities, and how they unite in quantum theory, Ekert concludes that we cannot avoid probability and complex numbers in describing the world. We cannot avoid quantum theory.

In a letter to Max Born[4] in 1926, Einstein said "Quantum theory yields much, but it hardly brings us close to the Old One's secrets. I, in any case, am convinced He does not play dice with the universe." I believe that Einstein could not accept the abandonment of predictive determinism that occurs in quantum theory. He could not accept the probabilistic nature of the theory. And yet quantum theory is one of the pillars of modern physics and underlies so much of modern technology. It works.

[2] Brooks (2017), who expounds the non-intuitive behaviours at the quantum scale in an amusing way.

[3] Ekert (2008) tells a story about a mathematician sitting in a café and watching an abandoned house across the street. After a while two people enter the house and a little time later three people exit. How interesting, thinks the mathematician, if another person enters the house it will be empty again.

[4] Max Born was Dame Olivia Newton-John's maternal grandfather, and a pioneer of quantum theory. The letter is dated 4 December 1926 and was translated by Irene Born Newton-John. See https://physicstoday.scitation.org/doi/full/10.1063/1.1995729

One of the scientific highlights of the past year has been the publication on 10 April 2019 by the Event Horizon Telescope of the first ever direct image of a black hole and its vicinity, the supermassive black hole at the core of the supergiant elliptical galaxy Messier 87, 53 million light-years away. By nature, black holes do not themselves emit any electromagnetic radiation other than the hypothetical Hawking radiation, so astrophysicists searching for black holes must generally rely on indirect observations. This image took two years of processing data from eight radio observatories recorded over ten days in April 2017.

Denisovans, extinct cousins of Neanderthals, have been known only by scraps of fossils from a Siberian cave, yet their genetic traces are found in modern humans, especially in Melanesia and Australia.[5] This year, scientists used a new protein method to identify a jaw bone from the Tibetan Plateau as Denisovan — the first physical trace outside Siberia.

[5] Genetic traces of Neanderthals (up to 2.5% of DNA) are found in all modern humans outside Africa.

Dr Len Fisher FRSN has agreed to join the Editorial Board of the *Journal*. Welcome, Len. The Editorial Board have given me advice and I should also like to thank Ed Hibbert, Rory McGuire, and Jason Antony for their help in preparing this issue.

Balmain, 20 December 2019.

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A Hebrew "Book within Book" at Fisher Library, University of Sydney

Gary A. Rendsburg

Rutgers University

Email: grends@rutgers.edu

Abstract

This article presents the first Hebrew "book within book" to be found in Australia. Included within the binding of an early printed Hebrew book entitled *Torat Moshe* (Venice, 1601), housed at Rare Books and Special Collections, Fisher Library, University of Sydney, is a small parchment fragment containing only nineteen Hebrew letters (comprising four complete words and portions of three others). The article traces the path from discovery (first observed by Alan Crown in 1984) to identification (a medieval poem recited on the occasion of the circumcision ritual). The poem is known from only five other medieval manuscripts (London, Oxford, Erlangen, Jerusalem, New York), so that the small Sydney fragment is a crucial, albeit fragmentary, witness to a rarely attested and thus relatively unknown piece of medieval Jewish history and liturgy.

Introduction

During the past several decades, researchers in (mainly) European libraries have discovered the remnants of medieval manuscripts within the bindings and flyleaves of early printed books. The practice of repurposing fragments of earlier manuscripts for the securing of bound books in the early centuries of printing was relatively widespread, especially since the sturdiness of the no-longer-needed (?) parchment scraps made for a readily available and highly effective resource.[1] Today there is a worldwide effort to identify and catalogue these fragments, which typically are in Latin, given that language's domination in medieval Europe.[2] In the vast majority of cases, the older parchment fragment found within the book binding contains a text already known to scholars, though naturally each witness thereto (even a fragmentary one) is precious in its own right.

As with Latin and other European languages (English, French, German, Greek, etc.), so too with Hebrew. Within the bindings and flyleaves of early printed books (both Jewish and otherwise), one finds a considerable amount of earlier Hebrew material on the parchment scraps and strips used to secure the books. A worldwide digital project, known as "Books within Books: Hebrew Fragments in European Libraries," has been established to aggregate all this material, thereby allowing scholars around the globe to learn of each other's discoveries. The project is directed by Judith Olszowy-Schlanger of the University of Oxford and the École Pratique des Hautes Études (Paris), with support from the Rothschild Foundation Hanadiv Europe, and is hosted at its

[1] For general introduction, with excellent images, see Hester (2018).

[2] The largest digital project is Fragmentarium: Digital Research Laboratory for Medieval Manuscript Fragments: https://fragmentarium.ms/. For a collection of essays on the subject, see Brownrigg & Smith (2000).

own dedicated website: http://www.hebrewmanuscript.com/.

Typically, the manuscript fragments reveal familiar texts: Bible, Mishna, Tosefta, Talmud of the Land of Israel, Babylonian Talmud, various collections of Midrashim, commentaries, etc. — though once again, each witness to an ancient or medieval text constitutes a precious treasure. On occasion, a less well-known text is revealed, in which case the manuscript fragment may have even greater intrinsic value.

As one can tell from the subtitle of the "Books within Books" project, the vast majority of the fragments are housed in European collections, even though the website includes (or will include, as more material is uploaded to the site) documents currently in Israel, Tunisia, Canada, and the United States. To the long list of countries registered at the "Books within Books" website, we now may add Australia.

Fisher Library

Fisher Library of the University of Sydney contains a fine collection of several dozen Hebrew manuscripts, Torah scrolls, incunabula, and other early printed books, all housed in its Rare Books and Special Collections division. The majority of these documents once were owned by none other than Sir Charles Nicholson (1808–1903), guiding light of the University during its early years, including service as its second Chancellor (1854–1862).[3] As is well known, the great polymath's interests spanned medicine and antiquities, and many points in between. Less well known is the fact that he also studied Hebrew, perhaps while younger, though certainly during the ninth decade of his life, as is indicated on the inside front cover of Fisher MS Nicholson 52 (his personal Hebrew lexicon, written in his own hand, as a learner's guide) where one reads the inscription, "While an octogenarian Sir Charles Nicholson was Studying Hebrew. G.E.S." (see Fig. 1).[4]

Alan D. Crown created a detailed typewritten catalogue of these documents during the 1970s and 1980s, entitled *Hebrew Manuscripts and Rare Printed Books, Held in the Fisher Library of the University of Sydney* (Sydney: Wentworth Press), 1st edition, 1973 / 2nd edition, 1984. Crown's descriptions of the individual documents retain their value until the present day.

As an aside, I note here that some of the Nicholson manuscripts and books previously were owned by the Duke of Sussex, Prince Augustus Frederick (1773–1843), son of King George III; others were owned by Alexander Lindsay, 25th Earl of Crawford (1812–1880); and still others were purchased from Moses Wilhelm Shapira (1830–1884).[5]

As I teach my students, each manuscript has multiple narratives: a) when, where, how,

[3] For general orientation, see Kirsop (2007).

[4] It is tempting to identify G.E.S. with George Salting, the Australian-born British art collector (1835–1909), with whom Nicholson was quite close, as suggested to me by Wallace Kirsop (Monash University), a student of Nicholson's career as a book collector (see previous note) (pers. com., 28 May 2019). As Professor Kirsop quickly added, though, Salting did not use a middle name or initial. An internet search revealed one such instance with middle initial E.: https://arcade.nyarc.org/record=b1109630~S7 — but this constitutes very slender evidence on which to build even a working hypothesis. Otherwise, the identity of G.E.S. remains elusive.

[5] For the Duke of Sussex and his library, see Gillen (1976, pp. 175–179), even if the author gives short shrift to the Duke's Hebraica collection. For the Earl of Crawford, see Barker (1978). For Shapira, see now Tigay (2017), esp. pp. 57–60 for connections to Charles Nicholson.

by whom, and for whom it was written (or in the case of incunabula, the parallel information); b) who owned the manuscript (or early printed book) over the course of the centuries; and c) how it came to reside in the library which serves as its present custodian.

During my recent tenure as Mandelbaum Visiting Professor at the University of Sydney (mid-March through mid-May, 2019),[6] I had occasion to inspect the entire collection, with Crown's catalogue always at my side.[7] If I may be permitted a personal aside, I should mention that I knew Alan Crown (1932–2010) relatively well (especially given the distance between our two countries), from our first meetings at the Oxford Centre for Hebrew and Jewish Studies (then housed at Yarnton Manor) during the 1990s through to my first visit to Sydney in 2004. Alas, Professor Crown died shortly before my second visit to Sydney in 2011. As I inspected the Hebrew manuscripts at Fisher Library, during this my third visit to Australia, with Alan Crown's catalogue in hand, it was, accordingly, like having an old friend serving as my guide.

Torat Moshe (Venice, 1601)

Attention is drawn here to the first printing of the complete Hebrew work known as *Torat Moshe*, lit. "The Torah of Moses," the Pentateuch with commentary by Rabbi Moses Alshekh (1508–1593),[8] based on his public sermons, printed in Venice by the well-known printer Giovanni Di Gara,[9] in the year 1601 (see Fig. 2). This item was not included in the first edition of Crown's catalogue, though it does appear in the second edition, on p. 30. When Crown wrote his description, the work was still uncatalogued (that is, it bore no shelfmark), though in the intervening years it now bears the designation RB 5101.2.

As far as can be determined, the book is not amongst the documents owned by Sir Charles Nicholson, for his book plate appears in all of those that he owned (save for the scrolls, obviously), and/or the accession documentation records his prior ownership. In the case of RB 5101.2, no book plate is present, nor is any other helpful information present, nor do the library records preserve any such information. Which is to say, the accession documentation seems to be lost in the mists of time.[10] As such,

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[6] During this two-month period I was associated both with Mandelbaum House (a residential college) and the Department of Hebrew, Biblical, and Jewish Studies, though I also should add that this was the third occasion on which I held this visiting position (prior visits were in July–August 2004 and February–March 2011). I here express my gratitude to both institutions for their warm hospitality, with special mention of Ms. Naomi Winton at the former and Prof. Ian Young at the latter. See also the next footnote.

[7] My research at Fisher Library was facilitated by the kind assistance offered by Julie Price, Julie Sommerfeldt, and Fiona Berry, librarians *par excellence* in Rare Books and Special Collections, to whom I express my deep gratitude. As always, my wife Melissa A. Rendsburg provided assistance in manifold ways, including offering another set of perspicacious eyes to detect various jots and tittles which otherwise may have escaped my attention.

[8] In Crown's catalogue, the author is referred to as Moses Alsheik. I have adopted the spelling of the surname Alshekh as it appears in the authoritative *Encyclopaedia Judaica*, 2nd ed. (Preschel and Derovan 2007). In the older *Jewish Encyclopedia* the surname is presented as Alshech (Friedländer 1906).

[9] For information on the printer, see Busi (2007).

[10] The usual array of handwritten notes (all in Hebrew) indicating prior ownership appear at the top of the title page (see Fig. 2) and in the blank flyleaf pages, both in the beginning and at the end (see Fig. 3 for one example). The latter mentions the city of Eibenschütz / Ivančice (Moravia), so that we know that the volume was present there c. 1800 (see caption to Fig. 3 for further details). My gratitude to Joshua Teplitsky (University of Stony Brook) for his reading of the

there is no direct connection between this early printed volume and Nicholson, but I thought I would begin the narrative (as I have done above) with information about the second Chancellor of the University of Sydney, for his persona and collection of Hebrew books and manuscripts nicely sets the stage for the present account.

Sidebar: *Torat Moshe*: Genesis (Constantinople, 1593)

Moreover, while not directly relevant to the current project, one cannot mention *Torat Moshe* by Moses Alshekh without the following short side excursion. Note my wording above, "the first printing of the *complete* [emphasis added] Hebrew work known as *Torat Moshe*", with reference to the Venice, 1601, edition. The word "complete" needs to be included here, because the first part of the commentary, relating to the book of Genesis only, was printed in Constantinople in 1593 (as noted by Crown, see Fig. 7).

This earlier printing constitutes a story in its own right. In brief, the earlier, shorter version of *Torat Moshe* was printed by the great Doña Reyna Nasi (1538–1599), wife/widow of Dom Joseph Nasi (1525–1579), appointed as Lord of Tiberias and Duke of Naxos by the Ottoman sultans. After her husband's death, Doña Reyna used the family fortune to establish a printshop in her palace "in Belvedere near the great city of Constantinople, under the rule of our lord, the great and powerful king, Sultan Murad [= Murad III (r. 1574–1595)], may his glory be exalted" (to quote the title page, for which see Fig. 4). To repeat, this earlier printing is not directly relevant to the topic at hand, but no one should ever pass up the opportunity to mention the printing press established by this aristocratic Jewish woman, Doña Reyna Nasi, in the late 16th century.[11]

long inscription. However, none of the information contained within the handwritten notes helps us in our quest regarding the accession of the volume to the University of Sydney Library.

The "Book Within Book" Fragment

And now for the "book within book" (see Figures 5 and 6), which already Crown recognised (see Fig. 7). I quote him here *in extenso* (for my comments, indicated by the superscript letters, see below):

> The volume is of interest for its binding which is original and is worthy of a full description. As with many Italian bindings of the period pieces of Hebrew manuscript have been incorporated into the spine. Manuscript pieces of the type have turned up in considerable number in a recent study of the Italian state archives at Cremona[a] and are regarded as a living Geniza.[b] Only a small piece of manuscript is visible in the spine of this volume where the leather casing at the base [*sic*][c] of the spine has crumbled. Here a thin piece of parchment has been used as a lining. The words
>
> *'ani zokher w.....*
> *'anokhi sh(w.....*
> *'at nst...*
>
> can be distinguished. These words are not found in such juxtaposition in the Old Testament so the source must be some other Hebrew text. Little can be said about the script from the few words to be seen other than that they have a Gothic

[11] For further information on Doña Reyna Nasi and on *Torat Moshe* by Moses Alshekh, see the delightful and informative essays by Brener (2016, 2017). I here express my deep gratitude to Ann Brener (Library of Congress) for her comments on the draft version of this article.

> angularity and look like the lettering to be found in German-Hebrew manuscripts of the thirteenth century. [Crown 1984, p. 30]

[a] Since Crown wrote these words in 1984, as indicated above, Hebrew "books within books" have been found throughout Europe and elsewhere, though clearly Italy still holds prime position in regards to both quality and quantity, no surprise given that Hebrew printing began in Italy.[12]

[b] Geniza is the Hebrew word for "storeroom." By far the most famous such storeroom is the Cairo Geniza located in the Ben Ezra Synagogue. During the period of the 1860s through 1890s, c. 300,000 documents dating mainly from the 10th–14th centuries were removed from the premises. About two-thirds of these are housed in the Cambridge University Library, while the other one-third are distributed among approximately seventy libraries and private collections in Europe, Israel, and North America.[13] To the best of my knowledge, there are no Cairo Geniza documents in Australia.

When the "books within books" documents first emerged in Italian libraries, the term "Italian Geniza" was coined. Once scholars realised that such documents were to be found throughout European (and other) collections, the term morphed into "European Geniza."

[c] The visible portion of the medieval manuscript is actually at the top of the spine, not the base. Crown was an expert Hebraist, so this is not a case of holding the book the wrong way; rather it must be simply an honest mistake.

When Crown produced his catalogue on the typewriter in the 1980s, it was difficult to switch back-and-forth between English and Hebrew, and even the addition of diacritical marks was a challenge. Accordingly, when I first read Crown's transcription, before inspecting the Hebrew itself, I was unsure about certain words and indeed letters.

'ani zokher w…..
'anokhi sh(w…..
'at nst…

Now that I have inspected the volume, especially its binding, I am able to present the Hebrew text here with greater accuracy:

אני זוכר ה[
אנכי שו[
את נסת[

In sum, the nineteen visible letters comprise four complete words and portions of three others. Upon seeing the text, I agreed with Crown's assessment that "these words are not found in such juxtaposition in the [Bible, and thus] the source must be some other Hebrew text." Fortunately, today we have an online database of all (or nearly all) Hebrew literature, created by the Academy of the Hebrew Language (Jerusalem), known as Maʾagarim (literally "gatherings, collections, databases"): https://maagarim.hebrew-academy.org.il/. This database, in turn, will serve as the basis for the Historical Dictionary of the Hebrew Language project, covering the entire 3000-year history of the language and its literature, in the same way that the *Oxford English Dictionary* surveys, details, and analyses the history of English.

For the nonce, however, scholars are able to access the database, both for its concordance and for its "free text" search. I selected the two-word phrase אני זוכר *ʾani zoker* "I remember" from the above snippet, since this is the only legible portion of the document containing at least two complete words, and entered the selection into the "free text" search window. My attempt was immediately rewarded. The fifth "hit" under this operation yielded the desired composition (see Fig. 8). Note that the highlighted words אני זוכר *ʾani zoker* "I remember" are followed by strings of letters that accord perfectly with what is legible in our binding fragment.

Through this operation, I learned the identity of the text: a *piyyuṭ*, or liturgi-

[12] For details, see Hill (2013).

[13] For general introduction, see Hoffman & Cole (2011).

cal poem, on the occasion of a baby boy's circumcision. What Alan Crown had not been able to uncover, I was able to identify with a few keystrokes. Such is the world in which we live today, with research tools at our disposal that earlier scholars could not have imagined. I must emphasize here that Crown's inability to identify the text, and mine as well, does not constitute a reflection of our scholarly abilities (or lack thereof), for as we shall see, our poem is rarely attested within the annals of Jewish liturgy, custom, and practice.

The Full Poem: "O God, I Recall the Covenant"

I further learned that the manuscript prototype for this *piyyuṭ* at the Maʾagarim database is British Library MS Or. 2772 (= Margoliouth no. 658), with the latter designation referring to George Margoliouth, *Catalogue of the Hebrew and Samaritan Manuscripts in the British Museum*, Part II (London: British Museum, 1905), pp. 278–281 (the first page of which is reproduced here, see Fig. 9).[14] The manuscript is a Jewish festival prayer book, according to the Ashkenazi (i.e., German) rite, dated to 1326. A perusal of the Margoliouth catalogue pages revealed that our little poem is labeled as no. 53 (see Fig. 10). This allowed for easier location of the poem within the large manuscript (310 folios), because the medieval scribe had numbered the individual components in the margin, using Hebrew numerals: in our case נג = 53. Once again, it is good to perform research of this kind in our contemporary world, because BL MS Or. 2772 is fully available online: http://www.bl.uk/manuscripts/Viewer.aspx?ref=or_2772. The poem is spread over two pages, fol. 200r (bottom) and fol. 200v (top) (see Figures 11 and 12).[15]

Through the Maʾagarim and British Library searches, I now had the full *piyyuṭ* at my disposal. Based on the usual method of entitling medieval Hebrew poems by their incipits, our poem is called אלהיכם אני זוכר הברית *ʾɛlohekɛm ʾani zoker hab-bərit* "O God, I recall the covenant." With this information in hand, I turned to the authoritative reference work of Israel Davidson, *ʾOṣar ha-Šira ve-ha-Piyyuṭ* = *Thesaurus of Mediaeval Hebrew Poetry*, 4 vols. (New York: Jewish Theological Seminary, 1924–1933), to determine if the poem is registered there — and indeed it is (Davidson 1924–1933, vol. 1, p. 209, no. 4571). Davidson's sources were three printed *siddurim* (sg. *siddur* = prayer book for daily and Sabbath use) and *maḥzorim* (sg. *maḥzor* = prayer book for festivals and special occasions): a) הדרת קדש *Hadrat Qodeš* "Holy Splendour" (Venice, 1599–1600); b) שער השמים *Šaʿar haš-Šamayim* "Gate of Heaven" (Amsterdam, 1717); and c) דרך החיים *Derekh ha-Ḥayyim* "Way of Life" (Stettin, 1862).[16] Below we will return to the earliest of these three printings,

[14] Margoliouth's project is a work of prodigious scholarship, reaching more than 1200 pages spread over four volumes, published between the years 1899–1915. For a comparable work, see below, n. 31. The reader will recall that British Museum manuscripts of this nature were transferred to the British Library upon the latter's official establishment in 1973.

[15] I here extend heartfelt thanks to Zsófia Buda, manuscript cataloguer at the British Library, Asian and African Studies, for her kind assistance. In the wake of my email to her (17 April 2019) about this manuscript, she very quickly identified the specific location of the poem on fols. 200r–200v, thereby obviating the need for me to search and scroll at the website.

[16] Davidson 1924–1933, vol. 1, p. 209, no. 4571, with cross-references to the sources listed on pp. liii, lxxxviii, and lx, respectively. (Davidson lists everything in alphabetical order, for easy referencing, while I have placed the three sources in chronological order).

the one from Venice, 1599–1600, though we jump ahead of our story.

Here follows the full poem, as presented in BL MS Or. 2772, with poetic lineation (as opposed to a layout per the manuscript lines); my attempt at an English translation; and my annotations marked by superscript letters. The scribe of BL MS Or. 2772 included the Hebrew vowels (per the practice with most prayer books, etc.), though I have omitted them here for simplicity's sake. In addition, the Hebrew text includes a special mark to indicate the end of a poetic line; I have transcribed that mark with the standard English full stop (period). Finally, note that the Hebrew poem includes a rhyme scheme, with each line ending in the syllable *-rit* (starting with the word *bərit* "covenant" in line 1), a technique which cannot be reproduced in English translation.

לברית מילה
אלהיכם אני זוכר הברית.
הנה אנכי שולח לשארית.
את נסתר בנחל כרית.
ופנה לפניו גוים יכרית.
מבשר טוב ושלום באחרית.
אומר לציון מלך אלהיך זהרית.
ובדברי

For the covenant of circumcision:[a]
O God,[b] I recall the covenant,
Behold, I send to the remnant.
The one hidden in the Cherith Brook.[c]
And he will turn towards him, destroying the Gentiles.[d]
Heralding good and peace[e] for the end-of-time.[f]
Saying to Zion, 'King, your God', shining-forth.
And with the words of.[g]

[a] Recall that in Judaism, circumcision is the sign of the covenant (see Genesis 17).

[b] Literally, 'your (pl.) God'.[17]

[c] The name of the brook where the prophet Elijah hid (1 Kings 17:1–7).[18] According to Jewish folklore, Elijah attends each circumcision, with an honorary chair set in place for him, hence, he is invoked here. In addition, according to Jewish tradition, Elijah is the harbinger of the Messiah,[19] as reflected in the following lines.

[d] Heb. *goyim*, lit. "nations," in this context, Gentiles. The role of destroying the Gentiles is not necessarily part of Jewish messianic expectation, but given the continuous attacks on Jewish life and religion in Christian Europe (blood libels, accusations of host desecrations, massacres by Crusaders, disputations, book burnings, expulsions, etc., etc.), one can understand the Jewish poet's hope that Elijah would avenge these actions.

[e] The Hebrew word *ṭov* "good" is written in the left margin of BL MS Or. 2772, fol. 200r, last line, added there after it was accidentally omitted by the scribe.

[f] The Hebrew term *ʾaḥarit* "end of time" refers here to the Messianic Age.

[17] The use of the form אלהיכם, lit. 'your God' (as opposed to "O God" or some other form), is characteristic of a specific genre of *piyyuṭ* which developed in medieval Ashkenaz. The word אלהיכם, lit. "your God," is invoked as an echo of the phrase אני יהוה אלהיכם "I am the Lord your God," which appears in the special Qeduša "sanctification" prayer for Musaf (additional service) on Sabbath and Festivals, at which point poems of this genre were inserted into the service (see also annotation [g] ahead). The three-word Hebrew phrase, in turn, occurs 34x in the Bible (28x in the Torah, 5x in the Prophets, and 1x in Judges), though in the present instance the Qeduša prayer cites Numbers 15:41. For numerous examples of *piyyuṭim* beginning with the word אלהיכם, lit. "your God," see Davidson 1924–1933, vol. 1, pp. 209–210, nos. 4563–4605. See also the nine such liturgical poems registered by Hollender (2005, pp. 297–298). For general discussion, see Fleischer (1975, pp. 448–449). For easy reference, see also the Wikipedia entry: https://en.wikipedia.org/wiki/Elohekhem.

[18] The Hebrew form of the name, כרית *kərit*, puns on the verb כ-ר-ת *k-r-t* "cut," since in Biblical Hebrew usage, one "cuts a covenant." See further below, n. 26.

[19] In the New Testament, this role is filled by John the Baptist, for which see Matthew 11:12–14, 17:10–13, Luke 1:13–17, etc.

[g] Each of the poems in this collection ends with this phrase, shorthand for ובדברי קדשך *u-b-dibre qodšəka* "and with the words of your holiness," thereby sending the precentor back to this point in the Qeduša prayer (see n. 17).

Additional Medieval MS Evidence for Our Short Poem

With the full poem now in hand, I next sought to determine whether this *piyyuṭ* is attested in other manuscripts, or whether the British Library manuscript is a unique testimony thereto (besides the later printed volumes registered by Davidson). If the latter, our little fragment, used in the binding of a book printed in Venice in 1601 and currently housed in Fisher Library, would gain much greater prominence.

My first step was to use Facebook at its best, via the Hebrew Codicology and Paleography group. Without disclosing my "discovery" (albeit via Alan Crown's groundbreaking work) of the binding fragment in Sydney, I simply asked members of the group if anyone knew of another attestation of our poem. Within minutes, Yisrael Dubitsky of the National Library of Israel (Jerusalem) (NLI) responded with the sought-after information. Using the NLI's database of Hebrew manuscripts, Ktiv: The International Collection of Digitized Hebrew Manuscripts (http://web.nli.org.il/sites/nlis/en/manuscript), Dubitsky was able to identify in short order three additional manuscripts that contain our poem for the circumcision ritual.[20] As he informed me, somewhat oddly BL MS Or. 2772 was not included in the Ktiv database (even though it served as the basis for the Maʾagarim database)[21] — but, to repeat, at least three other manuscripts include the poem.[22]

For the record, the three additional manuscripts are:

1. NLI Ms. Heb. 34o1114, an Ashkenazi *maḥzor* (prayer book for festivals and special occasions), dated to 1418 — with our poem on fol. 189v (see Fig. 13).[23]
2. Universitätsbibliothek Erlangen-Nürnberg, Erlangen, Germany, Ms. 1267, an Ashkenazi *siddur* (daily prayer book), Worms, 14th century — with our poem on fol. 220r (see Fig. 14).[24]
3. The Jewish Theological Seminary of America (J.T.S.), New York, Ms. 8972, an Ashkenazi *maḥzor* (prayer book for festivals and special occasions), dated to the 13th–14th centuries — with our poem on fol. 92b (see Fig. 15).[25] This version of

[20] Naturally, I was aware of the Ktiv project, but as I had not yet mastered its search capacity, I was and remain very grateful to Yisrael Dubitsky, especially since he works with the database on a daily basis. And not only for this gesture, but for an ongoing email exchange regarding the various manuscripts (April–May 2019).

[21] Those in the know will find this situation somewhat ironic, because the Ktiv project is run by the National Library of Israel, while the Maʾagarim project is directed by the Academy of the Hebrew Language, both located on the Givat Ram campus of the Hebrew University (Jerusalem). Moreover, the two buildings are about 500 metres from one another, a short seven-minute walk, which the present author has strolled on many occasions.

[22] Regarding my use of the phrase "at least," see ahead. Incidentally, binding fragments also are included in the Ktiv project, in addition to their availability at the Books within Books project, discussed above.

[23] Available at: http://beta.nli.org.il/he/manuscripts/NNL_ALEPH000044735/NLI.

[24] Information about this manuscript available at: http://beta.nli.org.il/he/manuscripts/NNL_ALEPH000170927/NLI. I here extend my thanks to Elisabeth Dlugosch of the Universitätsbibliothek Erlangen-Nürnberg for her kind assistance in obtaining the image which appears as Fig. 14.

[25] Available at: http://beta.nli.org.il/he/manuscripts/NNL_ALEPH003468718/NLI.

the *piyyuṭ* includes an additional five-word line inserted before the final line: ידעו זאת כל כרותי ברית "may all who cut the covenant know this."[26]

Now, the Ktiv project contains by far the largest database of Hebrew manuscripts in the world, but its search capacity is only as good and as up-to-date as the information contained therein (hence the phrase "at least three other manuscripts" used above). Which is to say, the information is continually inputted by devoted cataloguers and specialists, but each of the thousands of manuscripts must be studied for all its component parts, a lengthy and difficult process. This is especially true for *siddurim* and *maḥzorim* (where one would expect to find our *piyyuṭ*), since there was no fixed liturgical tradition within Judaism, with each community following its own rite, using different prayers, different versions of prayers, different orders of prayers, etc., etc. This stands in contrast, for example, to manuscripts of Bible, Mishna, etc., where the contents does not differ radically from one manuscript to the other, save for the order of the books or the tractates.

Hence, if the presence of אלהיכם אני זוכר הברית "O God, I recall the covenant" in BL MS Or. 2772 was not detected in the Ktiv search conducted by Yisrael Dubitsky, then perhaps there is another testimony to our poem in another manuscript somewhere.

My next step, accordingly,[27] was to contact Sarah Cohen, researcher and cataloguer of the Ezra Fleischer Institute for the Research of Hebrew Poetry in the Genizah, an ongoing project of the Israel Academy of Sciences and Humanities.[28] The Institute (named for the great Israeli scholar who founded the project, now deceased[29]) seeks to create a database of all poems, *piyyuṭim*, etc., attested in Hebrew manuscripts, from both the Cairo Genizah (per its name) and beyond.[30] Does the database, I asked, contain any additional witnesses to our poem, which I had not uncovered via the above-described steps (Ktiv, Maʾagarim, Davidson, etc.)? Cohen responded immediately to my query with a positive answer, yes, in one other manuscript, Bodleian MS Michael 573 = Neubauer, no. 1099, an Ashkenazi *siddur* c. 1400, with the latter designation referring to the standard catalogue, Adolf Neubauer, *Catalogue of the Hebrew Manuscripts in the Bodleian Library* (Oxford: Clarendon Press, 1886), cols. 303–306, no. 1099.[31] (See Fig. 16 for the catalogue entry and Fig. 17 for our poem as it appears in the manuscript.)

In sum, at the present state of our knowledge, the poem אלהיכם אני זוכר הברית "O God, I recall the covenant" is attested in five medieval Hebrew manuscripts: London (BL), Jerusalem (NLI), Erlangen, New York (J.T.S.), and Oxford (Bodleian).

26 Thus literally, with the Hebrew verb כ-ר-ת *k-r-t* "cut," per Biblical Hebrew usage. See also above, n. 18.

27 At the suggestion of Yisrael Dubitsky of the NLI.

28 The website of the Institute is: https://www.academy.ac.il/Branches/Branch.aspx?nodeId=830&branchId=348.

29 Ezra Fleischer (1928–2006): https://en.wikipedia.org/wiki/Ezra_Fleischer.

30 As such, the project is not intended to replace Davidson's *Thesaurus*, whose information derives almost exclusively from early printed books, but rather to augment it.

31 Neubauer's project is another work of prodigious scholarship, reaching more than 600 pages. For a comparable work, see above, n. 14. I here express my thanks to Rahel Fronda and César Merchán-Hamann (both of the Bodleian Library, Oxford) for their assistance regarding MS Michael 573, including procurement of the image in Figure 17).

Once More: The "Book within Book" Fragment

With this long expedition into the arcane but ever enlightening world of medieval Hebrew manuscripts, we now return to the small parchment fragment used to bind the first printing of the complete *Torat Moshe* held by Fisher Library. As indicated above, only nineteen letters are visible (see the transcription above), but they are sufficient to allow us to identify the text as a sixth (albeit fragmentary) copy of the medieval liturgical poem, אלהיכם אני זוכר הברית "O God, I recall the covenant," recited on the occasion of the circumcision ritual. Note that all five of the manuscripts described above emanate from the Ashkenazi orbit, with one of the five pointing ostensibly to Worms.

I say "ostensibly" here because, while the manuscript does not contain a colophon with explicit information regarding Worms, its contents reveal this to be the case. Worms was one of the major Jewish communities in the Middle Ages, along with its neighbouring cities Mainz/Mayence (to the north) and Speyer (to the south), and its specific liturgical traditions are well known and easily discernible. All three cities are situated on the Rhine River in modern-day Rheinland-Pfalz (Rhineland-Palatinate), with the remains of the medieval Worms and Speyer communities in particular still very much visible (cemetery in Worms, synagogues and ritual baths in both cities, etc.). The present writer has had the opportunity to visit the three cities on several occasions (most recently, with his wife Melissa, in June 2018).

The significance of the Ashkenazi provenance of the five aforementioned manuscripts is realised when we recall Alan Crown's description of the script, with reference to the "Gothic angularity [resembling] the lettering to be found in German-Hebrew manuscripts of the thirteenth century." With so little to go on, and with no knowledge of the other witnesses to our little poem, Crown was spot on, such was his expertise in codicological and paleographical matters.[32]

Moreover, I hasten to add that Crown's true expertise was in all matters Samaritan, including the scribal traditions of this small but important religious community.[33] Note further that the Samaritans use a different alphabet than the Jews, so that expertise in the one scribal system (in this case, the Samaritan one) does not automatically translate into expertise in the other (in this case, the Jewish one). And yet, to repeat, Crown was able to localise our parchment fragment based solely on the "Gothic angularity" of the 19 extant Hebrew letters.

In sum, this short poem was part of medieval Ashkenazi liturgical practice, recited on the occasion of the circumcision ritual, but it appears to have enjoyed no currency outside this German-centered community. Furthermore, the author of the poem, as with so many of the Jewish prayers, remains anonymous.

From Germany to Venice

So how did the small parchment fragment containing this poem reach Venice? The route is well known, per the description by Brad Sabin Hill: "Jews did not print in Germany in the 15th century, possibly due

[32] That said, Judith Olszowy-Schlanger (University of Oxford/École Pratique des Hautes Études), one of the foremost experts on Hebrew paleography, informs me that to her eye the script more likely derives from 14th-century Germany.

[33] See especially the edited volume: Crown (1989), which remains the basic reference work until the present day; along with the more specific authored work: Crown (2001).

to restrictions placed by the German guilds. The first Hebrew presses were founded in Italy, mostly by Ashkenazic Jews who had apprenticed with local Christian printers or learned of the art in Germany and moved south to practice" (Hill 2013, p. 233). One such German Jew, perhaps c. 1500 or perhaps later in the 16th century, brought his prayer book (in manuscript form) with him to Italy; a century later, or some decades later, with printed ***siddurim*** and ***maḥzorim*** now readily available, the old manuscript was cut up for reuse, with the parchment strips now serving to reinforce the spines and flyleaves of bound books.

With this information at hand, we return to the aforementioned ***Hadrat Qodeš*** "Holy Splendour" volumes, a large two-part ***maḥzor*** printed in Venice in 1599–1600, for which Davidson had recorded the presence of our little poem אלהיכם אני זוכר הברית "O God, I recall the covenant". Important to note is the fact that, while printed in Venice, the liturgy contained within ***Hadrat Qodeš*** follows the Ashkenazi rite (as announced on the title page and per the contents), and not the Italian one. (See Fig. 18 for the title page, and Fig. 19 for the printed version of the poem.) Most striking, however, is the fact that this volume was printed by the selfsame Giovanni Di Gara, with whom our story began (see above).

We can, therefore, complete the picture with relatively high confidence. Our anonymous German Jew migrated to Venice, with his prayer book in hand; eventually this manuscript made its way into the printing house of Giovanni Di Gara. If said individual arrived late in the 16th century, perhaps he himself was employed in the printshop, assisting the master Venetian printer. In either case, the ***piyyuṭ*** for the circumcision ritual was incorporated into the large two-volume printed prayer book published under the title ***Hadrat Qodeš*** "Holy Splendour" (in vol. 1, p. 321a) (Venice, 1599); and with the manuscript no longer needed, two years later a fragment thereof was included in the binding of *Torat Moshe*, a commentary on the Torah by Rabbi Moses Alshekh (Venice, 1601).

Oh, to be transported back in time, more than four centuries ago, to witness the scene of printers with their movable type and bookbinders with their parchment scraps and other leather materials, all busy at work in the enterprise overseen by Giovanni Di Gara. Somewhere in that scene, our two books were created — and one of them eventually made its way to Rare Books and Special Collections, Fisher Library, University of Sydney.

Is there more of our poem אלהיכם אני זוכר הברית "O God, I recall the covenant" to be found within the binding of the Fisher Library copy of *Torat Moshe*? Or are there additional Hebrew fragments, perhaps from another composition, to be found therein? Presumably yes, though herein lies a crucial issue: would anyone wish to dismember an original book binding from 1601 to learn the answer?[34] The binding too is a work of art (in addition to Figures 5 and 6, see now also Figures 20 and 21), so for the moment, the question rests without an answer. Perhaps one day, indeed one day soon, an emerging technology will allow penetration through the outer binding to reveal the layers that lie below.[35]

[34] Though I realise that some people have performed such operations to reveal more manuscript fragments.

[35] In fact, should the underlying text ever be read, and should more of the poem אלהיכם אני זוכר הברית 'O God, I recall the covenant' be present, it would be very inter-

For example, while I do not know whether the required technology is the same or not, given the variables (ink, age, etc.), one nevertheless may point to the recent "virtual unrolling" of the burnt Hebrew scroll found in the Ein Gedi synagogue, revealed to contain the first two chapters of the book of Leviticus (see Figures 22–24). The scroll (dated to c. 300 C.E.) was excavated in 1970, but it was too brittle and fragile to unroll, and hence it sat in the Israel Antiquities Authority storehouse for 35 years, until computer specialists used micro-CT scanning in 2015 to expose its contents (Segal et al. 2016). I must imagine that such or similar technology would be able to penetrate book bindings of much more recent vintage.

From Venice to Sydney

Earlier, I intimated that if the sole additional medieval testimony to our poem in Fisher Library was the complete version of אלהיכם אני זוכר הברית "O God, I recall the covenant," in British Library MS Or. 2772, the significance of the small 19-letter fragment would rise exponentially. In the end, such is not the case, since, as seen above, three additional manuscripts (located in Jerusalem, Erlangen, and New York) were identified via the search engine at the Ktiv database, and then the Ezra Fleischer Institute database revealed another manuscript (Bodleian Library, Oxford).

Nonetheless, Australia can be proud that one of its largest libraries provides a relatively rare window into a time long ago and a place far away. To be sure, this small manuscript fragment is the first Hebrew "book within book" item to be found not only in Australia, but within the southern hemisphere.[36] Such was my main purpose in writing this article: to publicise this point.

As the article developed, however, it attained an additional, somewhat unexpected goal: to demonstrate to interested readers the path of scholarship, especially in the digital age, emanating from a brief encounter with a small fragment of medieval Hebrew writing incorporated into the spine of a book by a bookbinder in Venice more than 400 years ago.

Acknowledgements

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esting to learn if the manuscript includes the reading reflected in the printed version of *Hadrat Qodeš* "Holy Splendour." For the different recensions, see the captions to Figures 13, 14, and 15. Should such prove to be the case, the scenario presented herein would be confirmed by this final piece of evidence.

[36] I have uploaded the fragment to the Books within Books website, where scholars now may access the information. See Fig. 25.

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Illustrations

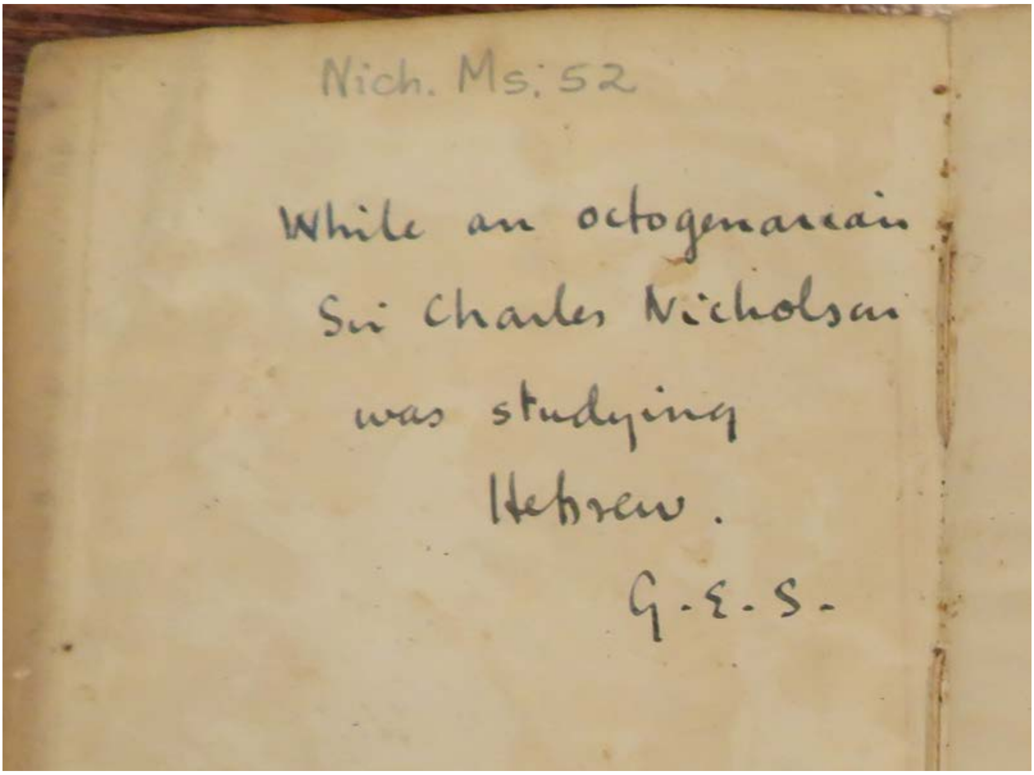

Figure 1: Inside front cover of Fisher MS Nicholson 52, personal notebook with simple Hebrew lexicon handwritten by Charles Nicholson whilst he was learning Hebrew, presumably sometime after 1885. (Photo credit: Gary A. Rendsburg — used with kind permission of Rare Books and Special Collections, The University of Sydney Library.)

Figure 2: Title page of Moses Alshekh, *Torat Moshe* (Venice: Giovanni Di Gara, 1601), first printing, in the University of Sydney Library collection. (Photo credit: Gary A. Rendsburg — used with kind permission of Rare Books and Special Collections, The University of Sydney Library.)

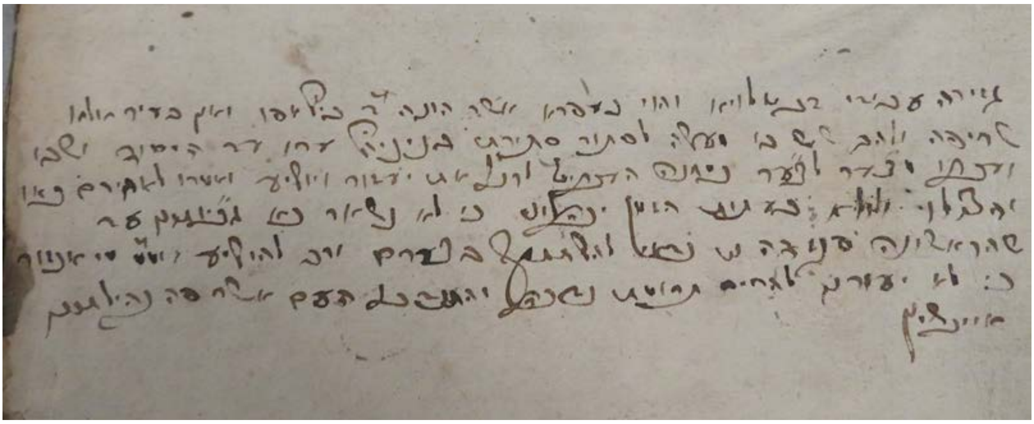

Figure 3: Handwritten note, in Hebrew, on the back flyleaf of Moses Alshekh, *Torat Moshe* (Venice: Giovanni Di Gara, 1601), first printing, in the University of Sydney Library collection. The inscription appears to be the lament for a Jewish community destroyed, with citation of Psalm 137:7. The last phrase reads כל העם אשר פה קהילתנו אייבשיץ 'all the people who are here (in) our community of Eibenschütz' (= Ivančice, Moravia). This information allows us to place the volume in a particular locale c. 1800, but it does not assist us in our quest to understand how the book reached the University of Sydney Library. My gratitude to Joshua Teplitsky (University of Stony Brook) for his reading and deciphering of this ownership note. (Photo credit: Gary A. Rendsburg — used with kind permission of Rare Books and Special Collections, The University of Sydney Library.)

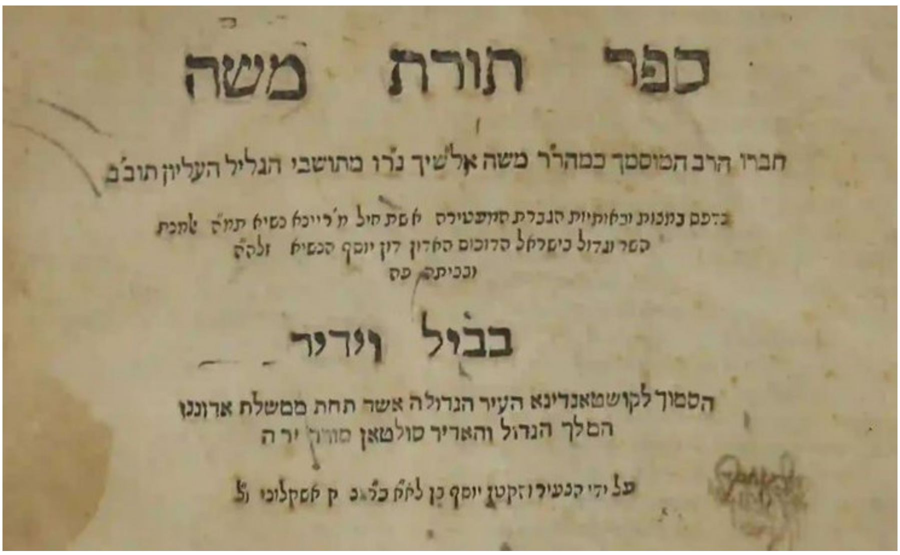
ספר תורת משה
חברו הרב המוסמך כמהר"ר משה אלשיך נר"ו מתושבי הגליל העליון תובב"א
הסמוך לקושטאנדינא העיר הגדולה אשר תחת ממשלת אדוננו
המלך הגדול והאדיר סולטאן

Figure 4: *Torat Moshe*, earlier version, containing the commentary to Genesis only (Constantinople, 1593), printed by Doña Reyna Nasi, who established a printshop in her home 'in Belvedere near the great city of Constantinople, under the rule of our lord, the great and powerful king, Sultan Murad, may his glory be exalted' (to quote the title page). (Source: https://tablet.otzar.org/, used with kind permission.)

Figure 5: The bound volume of Moses Alshekh, *Torat Moshe* (Venice: Giovanni Di Gara, 1601), first printing. Note the Hebrew manuscript fragment at the top of the spine. See Figure 6 for close-up. (Photo credit: Gary A. Rendsburg — used with kind permission of Rare Books and Special Collections, The University of Sydney Library.)

Figure 6: The Hebrew manuscript fragment at the top of the spine of the printed book, Moses Alshekh, *Torat Moshe* (Venice: Giovanni Di Gara, 1601), first printing. (Photo credit: Gary A. Rendsburg — used with kind permission of Rare Books and Special Collections, The University of Sydney Library.)

Uncatalogued

<u>TORAT MOSHE</u> (Pentateuch with Alsheik's commentary)

1st edition, Venice, 1601

Although this is a comparatively late work it is quite rare and even some long-established collections have no copy.

The author, Moses Alsheik, a rabbi and a bible commentator, died not long before this work was printed. The first part of Alsheik's commentary, also entitled *Torat Moshe*, was published in Constantinople in 1593, but it included only the book of Genesis. This is the first full printing of his commentary on the Pentateuch and it was undertaken by his son in 1601.

The volume is of interest for its binding which is original and is worthy of a full description. As with so many Italian bindings of the period pieces of Hebrew manuscript have been incorporated in the spine. Manuscript pieces of the type have turned up in considerable number in a recent study of the Italian state archives at Cremona and are regarded as a living Geniza. Only a small piece of manuscript is visible in the spine of this volume where the leather casing at the base of the spine has crumbled. Here a thin piece of parchment has been used as a lining. The words

'ani zokher w.....
'anokhi sh(w.....
'at nst...

can be distinguished. These words are not found in such juxtaposition in the Old Testament so the source must be some other Hebrew text. Little can be said about the script from the few words to be seen other than that they have a Gothic angularity and look like the lettering to be found in German-Hebrew manuscripts of the thirteenth century.

Figure 7: Catalogue entry by Alan Crown (p. 30). I have transcribed and annotated the long final paragraph (including the Hebrew transliteration) above.

5 <שו' 1> אלהיכם אני זוכר הברית.
<שו' 2> הנה אנבי שולח לשארית.
<שו' 3> את נסתר בנחל כרית.
<שו' 4> ופנה לפניו גוים יכרית.
<שו' 5> מבשר +[טוב] ושלום באחרית.
<שו' 6> אומר לציון מלך אלהיך זהרית.
$ובדברי$.

מראה מקום: אלהיכם אני זוכר הברית <שו' 1> | המסירה: London, British Library, 658

שם החיבור: **פיוט לברית מילה** | מחבר לא ידוע | זמן החיבור: אחרי שנת 1100 | סוגה: פיוט ותפילה

Figure 8: The fifth 'hit' at the Ma'agarim database (https://maagarim.hebrew-academy.org.il/), upon my searching for the two-word string אני זוכר 'I remember'.

On the last page are the following notes relating to changes of owners :—

1. (the first line being almost entirely cut away):—

אני · · · · · שמכרתי זה המחזור למר' חנה בת
הר' יחיאל ז"ל וקבלתי דמיו וכל מי שיערער על
מכירה זאת יהיו דבריו בטלי' ואין בהם ממש כי
נתפרעתי ממנה מכל וכל עד שוה פרוטה ולמען יהיה
עדות וזכות וראיה כתבתי וחתמתי שמי פה היום יום
ה' כג' לאדר השני רס"ו לפק"† והכל שריר וקים
אליעזר בר דוד ז"ל

2. כ"ג אדר הראשון רפ"ה‡

מודה אני ח"מ איך שנתתי המחזור הלז לבני יקותיאל···
במתנה גמורה ולראייתן חתמתי
שמי · · · פה · · ·

נאום חנה בת ר' יחיאל ז"ל מודה ומקים כל הנ"ל

The lady's signature is clear and betokens character.

658.

Or. 2772.—Vellum, about 7⅜ in. by 6, consisting of 310 leaves, with 16 lines to a full page. Most quires contain eight leaves each, but some few have six or ten leaves. The quires are marked by catchwords at the end, and also by signatures in a western style of enumeration. The first number in the original foliation (at the bottom of the pages) is 128, showing that the first 127 leaves have been lost. Leaves are also missing after foll. 304 and 307, and at the end. No. 246 has been omitted from this

roneous, *vide infra*) the first year is [50]74 (A.D. 1314). The edges have been too closely cut.

A large portion of a מחזור of the German rite containing the following Services :—

I. The תפלות for שחרית and מוסף of ראש השנה. Fol. 1*a*.

In smaller letters over יי' שפתי וכו' :—שומע תפלה עדיך כל בשר יבואו.—מוסף begins on fol. 7*a*.

II. The תפלות for יום כפור. Fol. 17*a*.

No כל נדרי is mentioned.

III. הושענות. Fol. 27*b*.

The order is as follows : 1. למען אמתך. 2. אבן שתיה. 3. אעריך שועי. 4. אום אני חומה. 5. ארם ובהמה. 6. אדמה מארר. 7. אל למושעות. 8. אדון המושיע. 9. אום נצורה (for שבת). 10. כהושעת אב המון השליך. 11. למען איתן. 12. תתננו לשם. 13. כהושעת אלים. 14. אנה אזון. 15. אל נא תעינו. 16. למען תמים בדורותיו. 17. תענה אמונים. 18. אז כעיני עבדים. 19. אבן לציון ישעך.

Marginal notes in cursive writing of probably the fourteenth century state that no. 2 is said on the second day of חול המועד, no. 3 on the first day of סוכות, no. 4 on the first day of חול המועד, no. 5 ביום שלישי של המועד, no. 7 on the second day of סוכות, no. 8 ביום הרביעי של המועד.

Figure 9: George Margoliouth, *Catalogue of the Hebrew and Samaritan Manuscripts in the British Museum*, Part II (London: British Museum, 1905), p. 278, the first of four pages detailing BL MS Or. 2772 (= Margoliouth no. 658). (Used with permission granted by the British Library.)

(לשבת בראשית). 49. אלהיכם יזריח (לשבת
וראש חדש). 50. אלהיכם זרוייו יאסוף (לברית
מילה). 51. אלהיכם יוסיף ידו (לשבת נחמו).
52. אלהיכם יבא משיחו. 53. אלהיכם אני זוכר
(לברית מילה). 54. יום שבת זכור השמיע.
55. לשבת וראש חדש אומ' זה י') בשבתות ובחדשים
(ומבליעים בתוך יום שבת זכור). 56. טפח שמים
(קודם מנן אבות ' לוה עלי ואני אפרע[b]). 57. בנר

Figure 10: George Margoliouth, *Catalogue of the Hebrew and Samaritan Manuscripts in the British Museum*, Part II (London: British Museum, 1905), p. 279b (bottom), with indication of our short poem as item no. 53 in the list. (Used with permission granted by the British Library.)

Figure 11: British Library MS Or. 2772, fol. 200r (bottom), with the rubric and first four lines of the poem (the opening word is written extra-large). Note also the Hebrew letters נג in the margin, serving as the numeral = 53. (Photo credit: © The British Library Board.)

Figure 12: British Library MS Or. 2772, fol. 200v (top), with the final two lines of the poem and the rubric. (Photo credit: © The British Library Board.)

Figure 13: NLI Ms. Heb. 34°1114, an Ashkenazi ***maḥzor*** (prayer book for festivals and special occasions), dated to 1418 — with our poem on fol. 189v. This version lacks the initial word in line 2 of the poem, הנה 'behold', and uses a different form for the word 'I' (אני *ʾani* instead of אנכי *ʾanoki*), also in line 2. (Image: Courtesy of the National Library of Israel, Jerusalem.)

Figure 14: Universitätsbibliothek Erlangen-Nürnberg, Erlangen, Germany, Ms. 1267, an Ashkenazi ***siddur*** (daily prayer book), Worms, 14th century — with our poem on fol. 220r. This version changes the last word from זהרית 'shining-forth' to באחרית 'at the end-of-time', thereby repeating the last word in the previous line. (Image: Courtesy of Universitätsbibliothek Erlangen-Nürnberg, Erlangen, Germany.)

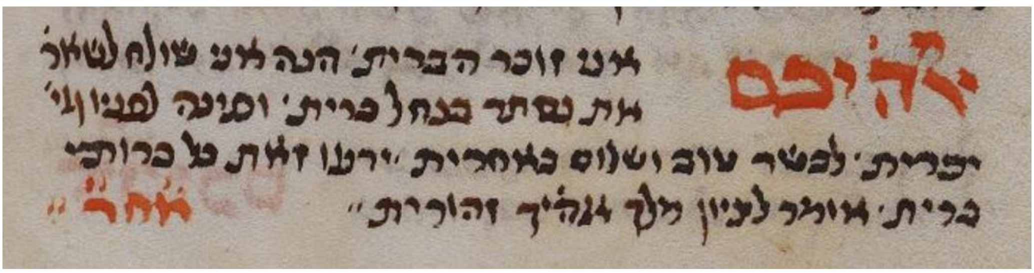

Figure 15: Jewish Theological Seminary of America, New York (J.T.S.), Ms. 8972, an Ashkenazi ***maḥzor*** (prayer book for festivals and special occasions), dated to 13th–14th centuries — with our poem on fol. 92b (bottom). This version of the ***piyyuṭ*** lacks the vowel points, includes an additional line (see above), uses אני ***ʾani*** 'I' instead of אנכי ***ʾanoki*** 'I', and reads the infinitive לבשר ***ləbaśśer*** 'to herald' instead of the gerund/participle מבשר ***məbaśśer*** 'heralding'. (Image: Courtesy of the Library of the Jewish Theological Seminary.)

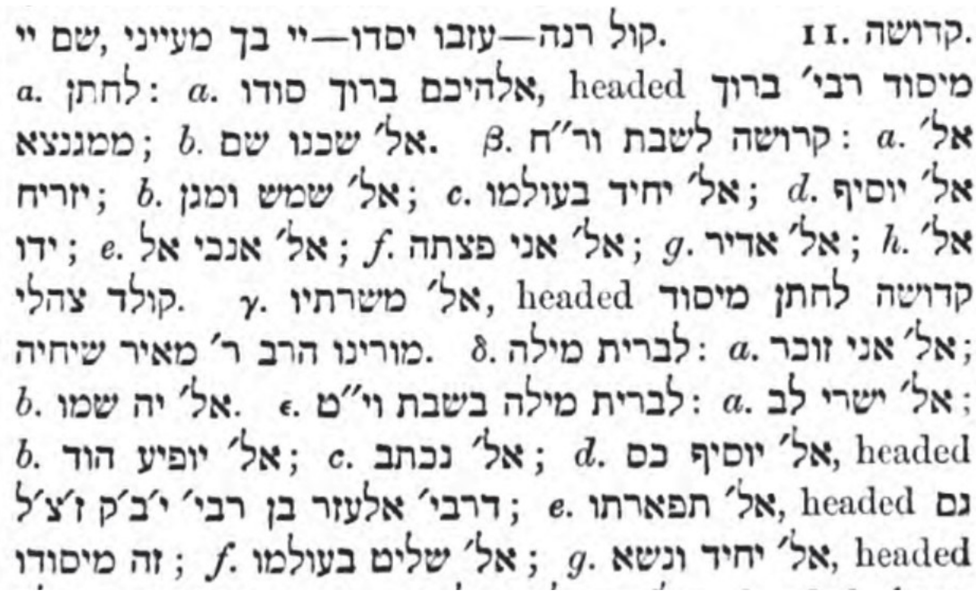
קרושה. 11. קול רנה—עזבו יסדו—יי בך מעייני ,שם יי
מיסוד רבי׳ ברוך headed ,אלהיכם ברוך סודו .a :לחתן .a
אל׳ .a : קרושה לשבת ור״ח .β .אל׳ שכנו שם .b ; ממנגצא
אל׳ יוסיף .d ; אל׳ יחיד בעולמו .c ; אל׳ שמש ומגן .b ; יזריח
אל׳ .h ; אל׳ אדיר .g ; אל׳ אני פצתה .f ; אל׳ אנכי אל .e ; ידו
קדושה לחתן מיסוד headed ,אל׳ משרתיו .γ .קולד צהלי
;אל׳ אני זוכר .a : לברית מילה .δ .מורינו הרב ר׳ מאיר שיחיה
; אל׳ ישרי לב .a : לברית מילה בשבת וי״ט .ε .אל׳ יה שמו .b
headed ,אל׳ יוסיף כם .d ; אל׳ נכתב .c ; אל׳ יופיע הוד .b
נם headed ,אל׳ תפארתו .e ; דרבי׳ אלעזר בן רבי׳ י׳ב׳ק ז׳צ׳ל
headed ,אל׳ יחיד ונשא .g ; אל׳ שלים בעולמו .f ; זה מיסודו

Figure 16: Adolf Neubauer, *Catalogue of the Hebrew Manuscripts in the Bodleian Library* (Oxford: Clarendon Press, 1886), col. 306b (near the top), with special attention to line 7, where the entry reads: δ. לברית מילה ['for the circumcision ritual']: a. אל׳ אני זוכר [an abbreviated form of the title of the *piyyuṭ*].

Figure 17: Bodleian MS Michael 573 = Neubauer, no. 1099, an Ashkenazi siddur c. 1400 — with our poem on fol. 145v. (Used with kind permission of the Bodleian Libraries, University of Oxford. Photo: © Bodleian Libraries, University of Oxford.)

Figure 18: Title page of ***Hadrat Qodeš*** 'Holy Splendour', Part 1, ***maḥzor*** for Sabbaths, Festivals, etc., according to the Ashkenazi rite, printed in Venice, 1599, by Giovanni Di Gara. The title page also indicates that within the volume are poems for special occasions such as weddings and circumcision rituals. (Source: https://tablet.otzar.org/, used with kind permission. Also available at: http://hebrewbooks.org/11581.)

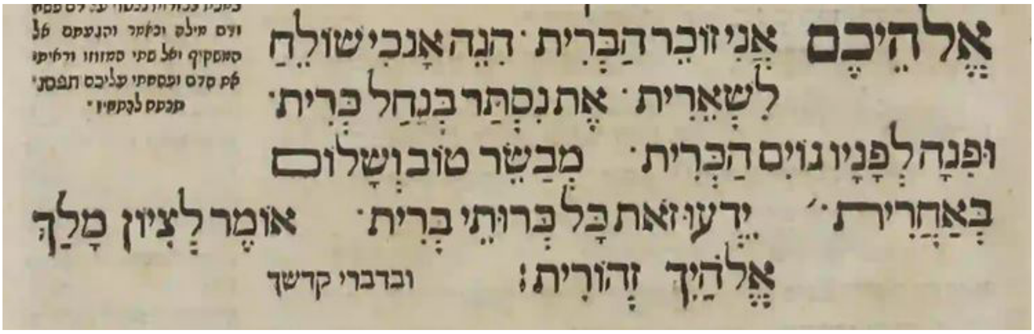
אלהיכם אני זוכר הברית · הנה אנכי שולח
לשארית · את נסתר בנחל כרית ·
ופנה לפניו גוים הכרית · מבשר טוב ושלום
באחרית · ירעו זאת כל כרותי ברית · אומר לציון מלך
אלהיך זהורית ׃ ובדברי קדשך

Figure 19: The printed version of אלהיכם אני זוכר הברית 'O God, I recall the covenant', in ***Hadrat Qodeš*** 'Holy Splendour', Part 1, ***maḥzor*** for Sabbaths, Festivals, etc., according to the Ashkenazi rite, printed in Venice, 1599, by Giovanni Di Gara, p. 321a. The printed version, incidentally, includes the additional line present in the J.T.S. manuscript (see above, Figure 15), plus there is a textual variant in line 4 of the poem, to wit, הכרית ***hakrit*** 'destroying' (infinitive serving as gerund) instead of יכרית ***yakrit*** 'destroy' (with future sense). (Source: https://tablet.otzar.org/, used with kind permission. Also available at: http://hebrewbooks.org/11581.)

Figure 20: Front cover of Moses Alshekh, *Torat Moshe* (Venice: Giovanni Di Gara, 1601), first printing. Somewhat worn, but its original beauty and workmanship is still discernible. (Photo credit: Gary A. Rendsburg — used with kind permission of Rare Books and Special Collections, The University of Sydney Library.)

Figure 21: Back cover of Moses Alshekh, *Torat Moshe* (Venice: Giovanni Di Gara, 1601), first printing. Somewhat worn, but its original beauty and workmanship is still discernible. (Photo credit: Gary A. Rendsburg — used with kind permission of Rare Books and Special Collections, The University of Sydney Library.)

Figure 22: The burnt Ein Gedi scroll, discovered 1970, in the Byzantine-period synagogue at the site. (Image: Courtesy of the Israel Antiquities Authority.)

Figure 23: Image of the virtually unrolled Leviticus scroll from Ein Gedi, Israel, c. 300 C.E., produced by micro-CT scanning. (Image courtesy of Seth Parker, Digital Restoration Initiative, University of Kentucky, U.S.A.)

Figure 24: Reverse image of the virtually unrolled Leviticus scroll from Ein Gedi, Israel, c. 300 C.E. Published in Segal et al., 2016, p. 33. (Image courtesy of Seth Parker, Digital Restoration Initiative, University of Kentucky, U.S.A.)

Figure 25: Screen shot of the entry for RB 5101.2 at the website of the "Books within Books: Hebrew Fragments in European Libraries" project (http://www.hebrewmanuscript.com/). Registration is required for access to the database, though it is free. For our Sydney fragment, go to: http://www.hebrewmanuscript.com/bwb-database/collection-by-city/270.htm.

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The science of red meat and its importance to New South Wales: A case study

Benjamin W. B. Holman

Centre for Red Meat and Sheep Development, NSW Department of Primary Industries, PO Box 129, Cowra, NSW 2794, Australia

Email: benjamin.holman@dpi.nsw.gov.au

Abstract

Meat scientists are tasked to advance the red meat industry in New South Wales. This research has already provided valuable insights and measurable opportunities. Examples include investigations into Spirulina supplementation effects on lamb productivity and meat quality; optimisations to the precision and accuracy of laboratory-based meat science tools that reflect consumer experience; innovations in meat packaging technology; recommendations for long-term storage thresholds for frozen and chilled red meat; analyses of dark cutting and beef colour evaluations to predict carcass value; assessing the usefulness of novel colorimeters for meat colour appraisals; suggestions of novel forage-types that enhance red meat healthiness; and exploration of the means to accelerate the ageing process for beef. Each of these provides strong scientific foundations on which the New South Wales red meat sector can build to ensure meat quality and safety. This assurance is imperative to affirm market access, confidence and position; optimising production and processing efficiencies that mitigate economic and environmental cost; and boost the sector's social licence and broader recognition as a comparatively clean and green industry. Meat research must be dynamic so that New South Wales can benefit from its unique capability to deliver meat to match market specifications.

Keywords: Red Meat; Meat Quality; Smart Packaging; Preservation; Technique Optimisation; Consumer Appeal.

Introduction

Advancement of the red meat industry in New South Wales towards a secure and sustainable future deserves merit. In 2017, for example, this sector contributed approximately $17.2 billion to the State's annual turnover and provided a livelihood for more than 50,000 workers, many of whom live in rural communities (MLA, 2017). But beyond economic and employment value, advancement in the red meat industry is potentially more significant because it is engrained into our national identity. Australians are proud of our international reputation for clean, green and safe produce; we are active contributors to shaping the future of the red meat sector, and often claim patronage of its accomplishments (Coleman, 2018, Lockie, 2015). These historic links should not be taken for granted.

Meat scientists strive to improve and grow the red meat sector and doing so, remain committed to optimising both the consumer's experience and industry efficiencies. This includes research that identifies production system effects on red meat so as to: enhance its nutritional value (healthiness) and eating qualities; optimise meat storage practices to deliver superior preservation, reduce waste and permit greater market access and growth; find packaging technologies that boost retail-potential and intelligently inform prospective customers; and equip processors with methods to better achieve market specifications (both domestic and abroad). Holistic and practical innovation within these themes is vital and will deliver economic and societal benefits through a greater understanding of *science-in-agriculture*.

This paper aims to highlight some such recent achievements and share what has been their tangible benefit to the New South Wales red meat sector. Consequently, it should be recognised that this paper is a case study and does not aim to provide a definitive overview of all meat research presently undertaken in New South Wales. It should also be noted that in this paper, red meat is used to only refer to *bovine* and *ovine* meats (beef and lamb); other publications may use broader definitions.

Spirulina supplementation effects on lamb productivity and meat quality

Sheep raised for meat production can be categorised by their feeding systems, *viz.* extensive grazing systems that use traditional pasture mixes or intensive supplement-driven systems that use concentrate- or grain-based diets (Ponnampalam et al., 2016b). Whether a system is appropriate depends on animal genetics, feed resource availability, and market specifications. The implications from feeding system selection on muscle composition and meat quality traits are significant (Malau-Aduli and Holman, 2015b, Malau-Aduli et al., 2016). It is therefore important to validate the impacts of *novel* feed-types and supplements prior to their adoption. The edible cyanobacterium Spirulina (*Arthrospira platensis*) is one such novel feed-type — primarily due to its protein-rich content that includes many essential amino acids, vitamins, minerals, and fats (Holman and Malau-Aduli, 2013). This application as a livestock feed is further enhanced by Spirulina having better land- and nutrient-use efficiencies when compared to conventional feed-types (e.g. maize, wheat, barley, etc.) (Smetana et al., 2017). Furthermore, Spirulina is produced within nutrient-rich, liquid mediums and this has prompted its use to recapture nutrients otherwise lost to current waste streams (Dismukes et al., 2008). It is therefore unsurprising that Spirulina has been the focus of recent investigation.

Past research has reported several important observations when crossbred Merino lambs held under drought or non-drought conditions, were supplemented daily with one of three different Spirulina levels (Holman et al., 2014d, Holman and Malau-Aduli, 2014a). Lamb haematological metabolite profiles demonstrated that Spirulina supplementation had no detrimental impact on animal health and welfare traits (Malau-Aduli and Holman, 2015a). Indeed, the muscularity and growth-linked metabolites, creatinine and *Y*-glutamyl transferase, were observed to *increase* with Spirulina supplementation (Malau-Aduli and Holman, 2015a). This was supported when lambs fed 100 g of Spirulina per day were observed to have superior growth rates and body condition scores to the control lambs (Holman et al., 2012, Holman et al., 2014c). It should be noted that this outcome was found in spite of Spirulina having no observable effect on lamb feed intake – that is, its supplementation was not causing animals to consume additional basal feed resources (Holman and Malau-Aduli, 2014b). Genetic-nutrition interactions were apparent as SNP frequencies within the *ovine* ADRB3 and other genes indicative of lean carcass composition found to vary with Spirulina supplementation, and then more so when lambs were held under drought conditions (Kashani et al., 2015a, Kashani et al., 2017). These observations were confirmed through examinations of *M. longissimus lumborum* intramuscular fat content wherein levels declined with Spirulina supplementation (Holman et al., 2014b). That said, the polyunsaturated fatty acid content of the remaining fat content did *increase* to support the conclusion of Spirulina's benefit to improving the nutritional value of lamb (Kashani et al., 2015b).

Together, these outcomes suggest that Spirulina can be adopted into existing feeding systems to improve lamb productivity and the achievement of meat quality objectives. Furthermore, the prevailing dry conditions and inconsistent feed availability experienced by many New South Wales lamb producers in recent times, emphasise the need for practical alternative and novel feed-types, such as Spirulina, to ensure economic and community persistence.

Validation of red meat eating-quality measurements

The quality of red meat is fundamentally determined by its appeal to consumers and their *subjective* eating experiences. To better understand the appeal of red meat, consumer responses are often defined as *major sensory characteristics*, being: 1) tenderness, which is the mouthfeel or texture of the cooked meat; 2) flavour, the combined perception conveyed by the senses of smell and taste; 3) appearance or colour when the red meat is retailed or displayed; and 4) juiciness or the moistness experienced/induced upon mastication (Ponnampalam et al., 2016b). A consumer sensory panel (trained or untrained) can be used to measure these traits. However, to capture reliable and robust data, such panels can be relatively time-consuming and expensive. As a result, meat scientists often use laboratory-based proxy measures to quantify these traits. But, as true for all instrumental measures, their usefulness ultimately depends on understanding their reproducibility and representativeness — alternatively, their accuracy and precision.

Shear force (SF) is a measure of the effort necessary to sever muscle fibres and is a routine instrument-based measure used as a proxy for the sensory testing of tenderness. Its association to meat myofibril structure and fat content has been confirmed using small angle X-ray scattering synchrotron technology (Hoban et al., 2016) and laser diffraction particle size analyses (Silva et al., 2018b). In addition, abattoir effects on carcass pH and temperature declines have been shown to be important factors that influence SF values and therefore perceptions of meat tenderness (Hopkins et al., 2015b). However, a survey of the SF methodology in articles published in peer-reviewed animal and food science journals found these were, in general, not comprehensive enough to permit correct result interpretation nor research repeatability (Holman et al., 2016a). It is likely that this failure could stem from an acknowledged non-standardised approach to SF determination *viz.* differences between method endpoint temperatures and cook method, tenderometers, blade type and crosshead speed selection, reported resistance and unit, fibre orientation, etc. (Holman et al., 2016a). Our research efforts to identify sources of variation in SF measures have prompted the identification of six technical replicates as the lower limit for satisfactory result precision (Holman et al., 2015a). Sample block status (frozen or thawed) and weight prior to preparation were found to be important sources of variation that should be included when reporting SF results (Holman et al., 2017d). Furthermore, meat sample preparation method (e.g. grill, microwave, *sous vide*, etc.) will influence SF values and also the degree to which these results reflect consumer panel opinion (Silva et al., 2018a). The adoption of these findings could provide meat researchers the tools to achieve a greater understanding of consumer preference.

Likewise, the methods for instrumental measurement of meat colour are not standard, most likely because of the variety of technologies applied to this task (Tapp et al., 2011). This should be considered when comparing research findings as even instrument aperture size, Illuminant and standard observer settings, and the muscle fibre orientation on the measured surface have each been shown to impact on colorimetric variability. Larger aperture sizes, Illuminant A and 10° observer settings, and myofibrils orientated perpendicular to the measured surface are found to best *capture* red meat colour (Holman et al., 2015b, Holman and Hopkins, 2015, Holman et al., 2014a). The value of optimising colour measurement precision is based on the common knowledge that consumers prefer red meat with a bright red colour and the need for an instrument-based, objective definition for this trait. To fulfil this requirement a web-based survey was designed to distribute standardised photographs of beef with known colorimetrics. (Holman et al., 2016c). More than 2500 respondents from around the globe then ranked these images and provided the data necessary to establish that when a^* values (being a measure of relative redness) were equal to or above 14.5, beef colour may be considered as acceptable (Holman et al., 2017c). Furthermore, demographic effects on this threshold proved negligible, although respondent nationality and gender did contribute to variation in the relative importance of colour to beef value. These results are valuable to assist in the correct interpretation of instrumental colour measures in terms of consumer colour appeal.

The *drip loss* of beef has been used to understand the juiciness trait of meat, more recently determined using the EZ-Drip Loss method (Christensen, 2003). This method was designed for use with pork, so it was necessary to confirm its suitability for beef. As such, we found an additional 48 hours of incubation was necessary to differentiate between beef ageing groups (72 hours in total) (Kilgannon et al., 2018). As a result, New South Wales beef processors are now better informed when using this tool to estimate consumer perception. In addition, lipid oxidation in red meat is often quantified using a thiobarbituric acid reactive substance (TBARS) assay, a process ostensibly providing insight into flavour and other organoleptic quality traits. In practice, this has resulted in several TBARS thresholds that supposedly prescribe consumer opinion of overall liking of a red meat product (Campo et al., 2006). But research has shown that when two different methods of TBARS quantification were compared, no relationship between the results of these methods was observed (Zhang et al., 2019). Furthermore, neither of the results of the aforesaid two TBARS methods had a significant association to beef sample flavour liking and intensity, nor overall liking when evaluated using an untrained consumer panel (Zhang et al., 2019). This suggests that untrained consumers cannot detect abnormal flavour development due to high levels of TBARS, an outcome potentially resultant from the *halo effect* — being the misevaluation of an organoleptic trait as a result of the bias or influence of another (Larmond, 1977) — which is common to untrained sensory panels. Consequently, the New South Wales red meat industry should use caution if adopting a TBARS limit to describe beef shelf-life and retail potential.

Nutritive value and eating quality of Australian lamb cuts

The prevalence of *heavy* lambs (> 25 kg) in the New South Wales flock has increased because of advances in animal genetics and production efficiencies. While this outcome may have resulted from carcass weight being used to calculate carcass value and thus financial returns to the producer, heavier carcasses are often discriminated against because of their relative fatness and concerns regarding cut fabrication (Hopkins et al., 1995). Specifically, when boned out, a heavier carcass will produce portions of excessive size and of a retail cost that is unsuitable for modern households and unacceptable to the customer (Fowler et al., 2018). To overcome this challenge, it seemed productive to obtain a wider understanding of fabrication techniques in lamb and other livestock species, and use these insights to improve the retail potential of larger lamb carcasses. The publication of an "Information Matrix for Cuts-Based Grading" (Hopkins et al., 2015a) provides this information; summarising lamb-cut eating quality traits, nutritional value, recommended cooking method and portion, and unique fabrication opportunities that merit commercial attention. It was apparent, however, that our understanding of these characteristics was not comprehensive, with paucities evident for many common lamb cuts (Hopkins et al., 2015a). These omissions could have implications on the access of New South Wales lamb to international markets (e.g. European Union, South Korea, Japan, etc.) where consumers use nutritional, culinary and animal background information to evaluate the worth of lamb (Fowler et al., 2018, Holman et al., 2016b). Hence, more research is required.

Innovations in meat packaging technology

Red meat packaging has evolved from its traditional role as an inert barrier that protects its contents from contamination and spoilage (Holman et al., 2018d). Recent innovation has now designed complementary functions that enhance packaged meat quality, longevity and/or retail-potential. These can be defined using the term *smart packaging* (Kerry et al., 2006). In practice, smart packaging includes antimicrobial and antioxidant coatings and inserts; sensors that communicate the degree of freshness or spoilage of the packaged meat; engineering customisations that advance consumer-ease, packaging integrity and durability; leak and tamper-proofing technologies; and more sustainable material options to mitigate environmental impacts (Holman et al., 2018e, McMillin, 2017). The adoption of these emerging packaging technologies could prove advantageous to the New South Wales red meat industry and promote competitive access to important but geographically distant export markets.

Nevertheless, several key observations, outlined by Holman et al. (2018d), should be considered when exploring smart packaging responses to current industry challenges. For instance, the cost of implementation is a common hurdle for all such packaging responses. Costs may be reduced through improved economies of scale, device simplification and disposability. In terms of red meat, the smart packaging user should be clarified prior to its adoption so the connectivity and potential impacts of the user-interface on its retail performance are understood. In addition, legislative requirements for packaging differ between markets and may influence product access to the detriment of a continued or uninterrupted supply chain. Secondary effects of smart packaging must be clearly defined prior to usage: does a packaging solution that improves shelf-life at the expense of eating quality traits constitute a suitable technology? Lastly, many smart packaging options have been repurposed from other applications (e.g. medical and engineering fields, etc.) than for red meat packaging, creating an imperative that this latter application be tested *in situ* and compared to conventional packaging to establish a potential advantage (Holman et al., 2018e). From these reviews, we can recommend that the State red meat industry stakeholders consider packaging as part of a broader solution to managing current challenges. Further, these same stakeholders should ensure that the actual and economic contributions pertaining to *all* packaging are understood prior to adoption and implementation.

Effect of forage type on lamb productivity and product quality

New South Wales sheep producers that use extensive feeding systems would benefit from the identification of new forage types that have high protein and low cellulose and hemicellulose contents (Fraser and Rowarth, 1996). These characteristics promote animal growth rates, carcass weights and the efficient use of natural resources. However, past research has reported that some forages used as *novel feed-types* have had a detrimental effect on red meat organoleptic and shelf-life traits (De Brito et al., 2017b, Ponnampalam et al., 2016a).

To explore these outcomes, a total of sixty-two White Dorper lambs were finished on bladder clover, brassica, chicory + arrowleaf clover, lucerne + phalaris, or lucerne forages before being slaughtered and their *M. longissimus lumborum* and *M. adductor femoris* sampled (De Brito et al., 2016). These were sectioned and assigned to ageing periods (5, 12 or 40 days) where they were vacuum-packaged and held under refrigeration prior to testing. Lambs fed chicory + arrowleaf clover or lucerne forages had the highest carcass fat depth and dressing percentages. Bladder clover finishing resulted in increased glycogen content in the *M. longissimus lumborum*. However, no other meat quality trait, measured either within the laboratory or using an untrained consumer sensory panel, was observed (De Brito et al., 2016). The fatty acid profile and shelf-life metrics for these same samples were also analysed. It was found that chicory + arrowleaf clover resulted in the highest concentration of health claimable fatty acids, including the long-chain omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (De Brito et al., 2017a). Forage types with higher vitamin E levels showed lower lipid oxidation levels regardless of the ageing duration. Furthermore, sample retail colour stability was not influenced by forage type selection (De Brito et al., 2017a).

These findings were considered as a positive outcome, as animal productivity could be increased without any unfavourable effect on lamb-eating qualities and shelf-life. Moreover, forage selection could be used to improve the fatty acid profile and nutritional value of the lamb. This is pertinent as a high percentage of consumers have expressed a demand for lamb with higher levels of omega-3 fatty acids (62%) (Lamb et al., 2010). Even with this consumer trend, it should be noted that Australian lamb is yet to be overtly marketed in terms of its health claimable traits. Consequently, this information highlights the *niche* marketing potential available to New South Wales sheep producers in differentiating their product as a *healthy* option (Sinclair, 2007).

Identification of storage thresholds in frozen and chilled red meat

Frozen lamb and beef each represent a signification proportion of New South Wales exports to global markets, where geographic spread can make reaching them both expensive and time consuming (Malau-Aduli and Holman, 2014). Alternatively, red meat may be held *chilled* to enhance its eating quality and deliver a higher value product, albeit with a comparatively shorter period of preservation to the former method. Combining *chilled-then-frozen* storage could therefore permit quality enhancement associated with chilled storage before the frozen storage can be used to halt and preserve product appeal even after longer time periods (Coombs et al., 2017b). This could be valuable in managing product distribution and improving market access, matching production gluts more efficiently to instances of heightened demand, and promoting more cost-effective transportation.

To establish the effects of long-term chilled-then-frozen storage on red meat quality and safety traits, a total of 360 lamb loins and 48 beef loins were randomly taken from the boning rooms of commercial New South Wales abattoirs. These were vacuum-packaged (the beef first being divided into 4 equal portions); and held on-site for the duration of their assigned chilled storage durations (lamb: 0, 2, 4, 6 and 8 weeks | beef: 0, 2, 3 and 5 weeks). Samples were then frozen (if dictated and again on-site) before being transported to the 'Centre for Red Meat and Sheep Development: Meat Research Laboratory' where they were held for the duration of their assigned frozen storage periods (both: 0, 4, 8, 12, 24 and 52 weeks). Frozen storage holding temperatures were either –12 °C or –18 °C with freezers replicated. At the completion of their allocated storage treatment, each sample was tested for instrumental measures of sensory quality characteristics; display and shelf-life; microbial loading of key spoilage and safety organisms; lipid oxidation and fatty acid profiles; and protein degradation and oxidation markers (Holman et al., 2018c).

It was found that frozen holding temperature effects were negligible. This suggests that –12 °C could deliver comparable quality red meat to –18 °C across the storage periods examined in this study (Holman et al., 2017b). As –18 °C is conventionally used, if adopted, this result offers considerable energy-saving potential to the New South Wales red meat industry, reducing waste and environmental impacts because of improved long-term storage and transport efficiencies (e.g. slower shipping speeds, managing food wastage, etc.). That said, this observation should be applied using –12 °C as a "*maximum* temperature threshold" as industry would be best advised to use a lower frozen storage-holding temperature to allow a margin of error for unforeseen temperature interruptions.

Red meat quality parameters were shown to vary as a result of different chilled-then-frozen storage treatments, but when compared to existing consumer thresholds the variations were imperceptible (Holman et al., 2017a). Moreover, there was insufficient detection of key spoilage microbes in beef to allow for statistical analysis, possibly due to the hygienic and commercially representative LL[1] source, although variation in water activity, glycogen content, pH and other moisture parameters conducive to microbial proliferation were influenced by chilled-then-frozen storage (Holman et al., 2017a). Nevertheless, while lamb lactic acid bacteria, *Brochothrix thermosphacta* and *Enterobacteriaceae sp.* loads increased with *chilled* storage, the latter two types then declined as ensuing *frozen* storage duration continued (Coombs et al., 2017a). It should be noted that these microbial types are associated with meat spoilage rather than product safety.

Colour stability proved the exception as it became unacceptable earlier into retail display periods when either *chilled* or subsequent *frozen* storage periods were increased (Coombs et al., 2018a, Holman et al., 2017a). This is less of an issue while the end-product is destined for restaurants, food service or an additional value-adding process (e.g. sausages, mince, etc.), or when frozen product is retailed as is, instead of thawed prior to sale. Significantly, increased frozen storage periods produced beef fatty acid profile variations with unsaturated fatty acid levels declining as saturated fatty acid levels increased (Holman et al., 2018b). Polyunsaturated and health claimable fatty acid levels also tended to decline with increasing *chilled* storage period, albeit insignificant within the constraints of the experimental design (Holman et al., 2018b). This result needs to be verified as it has important ramifications for marketing New South Wales grass-fed beef as a *healthy* meal option. On analysis, other lipid oxidation markers, including peroxidase activity, TBARS and oxidation-reduction potential, reflected fatty acid profile variations (Coombs et al., 2018b). When compared against existing consumer thresholds, these suggest a perceptible increased marketability for red meat held under long-term frozen storage durations with the extent of the increase dependent on the preceding chilled storage period length.

Based on these observations, if New South Wales lamb and beef are effectively cold-chain managed so as to have low initial microbial loads, it can be held over long-term chilled-and-frozen storage. Permitting such storage durations would allow production and market demand variations to be stabilised without a reduction in tenderness, the development of rancidity or other adverse effects that contribute to a diminished perceived value (Coombs et al., 2016a, Coombs et al., 2016b). Such a management practice would counter claims of reduced quality due to the *chilled* product moving to a frozen state (e.g. accidentally frozen, etc.?) and then held for extended periods. Red meat display life or colour stability was found to deteriorate following either long-term chilled or frozen storage. Although this is not recommended, examples of *this practice* do exist in some export markets. Hence, it would be opportune to inform these markets of the likely negative effect on consumer acceptance and preferential purchase.

Optimising dark cutting and colour evaluation to predict beef carcass value

Dark cutting is problematic to the New South Wales beef industry and in an effort to discourage its prevalence, processors will generally discount and downgrade the value of these carcasses (McGilchrist et al., 2014). Their action is based on a preference

[1] The *longissimus lumborum* muscle, or loin. [Ed.]

for bright red beef and as dark cutting beef fails to match this criterion it is instead considered less fresh and of lower quality than normal beef. This fundamental difference results from dark cutting carcasses having insufficient glycogen reserves to drive *post-mortem* acidification which can impact on beef yield and quality characteristics.

Although different in other countries, in New South Wales, a trained operator will judge (grade) the exposed *loin surface* of a beef carcass as dark cutting or otherwise within the first 24 hours *post-mortem* (Ponnampalam et al., 2017). Common to all grading approaches is their use of a *single marker muscle* to grade and potentially discount the entire carcass. A comparison of three beef cuts from dark cutting and normal carcasses found that at least the bolar blade and potentially the forequarter of beef carcasses classified as dark cutting, did not reflect the negative attributes of the striploin and topside (Holman and Hopkins, 2019b). This outcome was supported by the differences in glycolytic derivate and pH declines observed between these same beef cuts (Holman, unpublished). Consequently, it is reasonable to conclude that components of a dark cutting beef carcass could be *salvaged* to regain a proportion of its undiscounted value. This could mitigate some of the associated economic and environmental impacts incurred from maybe not-so-inferior meat production.

Using a smart device app to improve objectivity of meat colour assessment

As previously stated, colour is an important factor in the evaluation and grading of beef carcasses, and conventional practice may involve subjective comparisons against standard references to gauge (dis)colouration. Due to the economic penalties associated with this assessment, it is important to be correct. The Nix Pro Color Sensor™ (NIX) is an inexpensive novel colorimeter that measures and transfers colorimetric data to a paired smart device (Nix Sensor Ltd., 2018). Red meat is not a homogenous substrate, so when testing the suitability of the NIX for beef analysis it was found that seven repeat measures are necessary to minimise response variation and contribute to improved precision (Holman et al., 2018a). When compared to another colorimeter, the NIX was found to capture colorimetric trends typical to display and ageing periods but had a lesser sensitivity than the widely used HunterLab MiniScan™. While this suggests a non-equivalency, the NIX remains a useful tool for red meat colour appraisal (Holman and Hopkins, 2019a). This notion was reaffirmed through its application in establishing a colorimetric threshold for distinguishing dark cutting beef carcasses. Based on the colour of the exposed *M. longissimus lumborum* (loin) surface between the 12–13th rib, carcasses found to have a chroma value equal to or greater than 30.5 were also dark cutters — permitting a degree of acceptable error (Holman et al., 2019). These findings are expected to be useful in providing the New South Wales red meat industry with an *objective* alternative to current methods of colour assessment: one that is simple, inexpensive and rapid. If adopted, this approach could prove valuable in reducing the costs associated with staff training and retention, ensuring against *subjective* misrepresentation, and *empowering* the industry to estimate other meat quality traits based on colorimetrics.

Accelerated ageing without compromising quality for beef

Consumers are willing to pay a premium for beef that is guaranteed as tender (Boleman et al., 1997, Feuz et al., 2004) and *ageing* beef provides a means by which New South Wales processors can capitalise on this opportunity. Currently, industry will routinely age beef for approximately two weeks to allow for enzymatic-mediated tenderisation. During this period the beef cannot be sold. This delay incurs many associated expenses (e.g. over-heads, storage requirements and lost opportunity) which could be reduced if the ageing procedure was to be accelerated. Past research has identified storage temperatures as important to ageing efficacy (Coombs et al., 2017b), these are often described as passive effects rather than those of an active management tool.

Recent research has aimed to establish time-temperature guidelines for industry to adopt for ageing beef so as to safely achieve improved beef quality within a reduced timeline. To test this, 320 beef M. *longissimus lumborum* portions were subjected to one of 72 unique temperature-time combinations (TTC) that were warmer and shorter than industry representative controls (~ 1 °C). From these it was found that beef can achieve comparable safety and eating quality, determined using both instrumental and untrained sensory panel analyses, in a shorter period of time to conventional practice if increased temperature is applied (Holman et al., 2018f, Kilgannon et al., 2019). However, based on current Australian safety guidelines (CSIRO, 1995), the authors instead recommended the adoption of shorter, cooler TTC that achieve the comparable outcomes (Kilgannon et al., 2019). These quality results were further supported by the analysis of volatile compounds released upon cooking and their known association with beef organoleptic characteristics (Kilgannon, unpublished). Research is ongoing into TTC effects on beef oxidative susceptibility and yield so that the commercial implications can be fully understood. Nonetheless, these findings have practical value within current industry safety and storage standards, and if adopted could minimise the resource requirement for producing high quality beef.

Conclusions

From these examples of research being undertaken in New South Wales, it is obvious that a scientific foundation is vital to uphold the wholesome reputation of New South Wales red meat across its global supply chain. Such research would improve red meat industry access to high value markets, achieve better information flow along their supply chains, advance lamb and beef eating quality traits in line with consumer expectations, and reduce associated production and processing costs. It should be noted that positive achievement in this sector extends well beyond the barbeque, but encompasses broad improvements to New South Wales economic and societal security. Recognition of these contributions should prompt a commitment that ensures continuous expert meat research capacity in New South Wales so that its red meat sector remains innovative and reactive to changing consumer demands. At least, the themes discussed above should encourage interest, conversation and contribution from the broader community into shaping the future of the red meat industry.

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Drawing in the Colony

Louise Anemaat

Executive Director, Library & Information Services and Dixson Librarian, State Library of NSW

Email: louise.anemaat@sl.nsw.gov.au

Abstract

Before photography, recording images required drawing or painting, and, without printing, reproducing images required copying by hand. This paper discusses drawings dating back to first European settlement in New South Wales, specifically a large collection of 745 zoological and botanical drawings from the 1790s which was bought by the State Library in 2011. Who were the artists? Which were the originals and which the copies? Answers are not easily obtained. We can however enjoy the images, very well preserved.

Introduction[1]

Our usual picture of the convict colony founded in January 1788 at Sydney Cove focuses, rightly, on extremes of hardship, isolation and punishment, the sudden dispossession of Indigenous cultures, on the environmental and psychological impacts of colonisation, isolation and distance.

The stories we tell are of crimes and misdemeanours, and the slow conquering of a landscape that at the time was considered both alien and inferior. Today the impression remains of a nation built on near starvation, suffering, floggings and hangings and a sense of utter futility.

But could our ideas about the First Fleet have become just a little lazy?

Of course, there is truth in these enduring stories. Life in the colony was without question a difficult, bewildering and alienating experience. The climate was harsh and unfamiliar, the environment was challenging and unpredictable. There were dire food shortages and rationing, and a crippling sense of isolation, of having been dumped, abandoned and forgotten, but there were also people who found the time and space to explore and observe, and to draw and record the strange new world that they found in NSW.

This has prompted us to look more closely at natural history drawings, and the practice of drawing during roughly the first twelve or so years of the colony.

Drawing in the Colony

Drawing started early in the colony. The first drawing likely to have been made in the colony was of a Grass Tree, drawn on 11 February 1788, just two weeks after the arrival of the fleet of eleven convict ships at Sydney Cove, by surgeon Arthur Bowes Smyth (Illus. 1).

The literature devoted to the art of Australia's First Fleet is thick on the ground and it is rare for new material to surface to add to the canon of existing drawings but this is exactly what occurred in 2011 when a large collection of 745 botanical and zoological drawings from the 1790s appeared on the market, from a private aristocratic library

[1] A lecture given at the Australian National Maritime Museum, on 15 June 2019, under the auspices of the Australiana Fund. The article is extracted from Anemaat (2014).

held at Knowsley Hall near Liverpool, England, and owned by the 19th Earl of Derby. The drawings had been compiled during the 1790s by a now forgotten but then widely known and acclaimed botanist, Aylmer Bourke Lambert. They were acquired for the collection of the State Library of NSW in 2011.

1: Grass tree or "A View of the Tree at Botany Bay, wh yields ye Yellow Balsam, & of a Wigwan," 1788/Arthur Bowes Smyth. Watercolour (Mitchell Library ML Safe 1/15 no. 6 FL1607156)

The emergence of these drawings prompted new, detailed art historical analysis of the traditions of natural history art production and its convention of copying and trans-Pacific dissemination. And I think it is fair to say that while we knew the collection was something special, we didn't quite know exactly what we had at the time.

What could the sudden emergence of a large, previously unknown collection of natural history drawings from NSW, add to our understanding of those early years of the colony?

We will look more closely at how this collection fitted in with other, known collections from the same period, why and how its appearance has made us look again at what we thought we knew.

The various sets and collections of watercolour drawings from the same period still present as a tangled knot of problems — drawings held privately, or held in collecting institutions in the United Kingdom, Germany, New Zealand and Australia.

Only some very, very few of the drawings are signed, and can therefore be formally ascribed to a small number of either naval and convict artists, or ships' surgeons. Attributions then are uncertain.

Two artists who consistently signed their drawings were Midshipman George Raper, who had a distinctive personal style; there is a lovely sinuousness in his drawings (Illus. 2). Thomas Watling, a convict with art training, also signed his work against the explicit instructions of his overseer and patron, First Fleet Surgeon-General John White. Watling had been transported for forgery, escaped en route at Cape of Good Hope, and eventually arrived in NSW in 1792.

2: "Bird and flower of Port Jackson," or Kookaburra (*Dacelo novæguineæ*), 1789/George Raper. Watercolour. (Raper Collection drawing no. 57. Natural History Museum, London)

Adding to the confusion is the fact that that the strong demand for images of new species amongst gentlemen, and occasionally women, amateurs of science in Britain meant that copying was rife — in England which is perhaps not surprising, but also in NSW, and possibly also on board, shared by officers on board returning ships, or even copied by Company Artists in India during stopovers.

Accordingly, art historians and curators have, for convenience, assigned comparable works into a couple of broad stylistic and temporal groupings: "The Port Jackson Painter" and "The Sydney Bird Painter," for instance.

Though each of these implies a single artist's hand at work, the Port Jackson Painter probably refers to at least six, possibly eight, different artists. The Sydney Bird Painter attribution refers to at least two people — one superior artist and one far less talented.

To complicate things even more, the early history and provenance of the drawings has for almost every collection become obscured. Some of these related collections have been held by cultural institutions for decades, for over a century, but the connections between them have largely gone unnoticed.

The Derby Collection

We now refer to the Knowsley Hall drawings as the Derby Collection for the 13th Earl of Derby (Illus. 3) who had purchased the collection in 1842, following the death of his friend, Aylmer Bourke Lambert (Illus. 4). Lambert had compiled the collection during his lifetime. The public emergence of this collection has been a little like finding that lost piece of a jigsaw at the back of the sofa. Comparing and considering this newly emerged collection of drawings alongside other known collections has shown them to be intimately interconnected.

The collection consists of 745 natural history drawings bound into six volumes. Half had not been seen since at least the 1940s; the existence of the other half was completely unrecorded.

3: Edward Smith-Stanley, 13th Earl of Derby, 1837/William Derby. Oil on canvas. Courtesy The Rt Hon. The Earl of Derby

4: Frontispiece Lambert (1803–07)

Three volumes we knew were well documented copies of drawings from the iconic Watling Collection compiled by John White who had lent his collection to botanist Alymer Bourke Lambert in 1797. Lambert then had White's drawings copied. Since

1902 the Watling Collection has been held in London's Natural History Museum while Lambert's copies have been in the Derby library since Lambert's death in 1842.

We know the background and contexts of many of Lambert's drawings because Lambert was such a prolific and enthusiastic letter-writer to his friend, James Edward Smith, founder of the Linnaean Society, London. Lambert's letters to Smith are now held in the Linnaean Collection. Lambert, Derby and Smith were friends and passionate enthusiasts for natural history.

Despite their extensive correspondence, three of the six volumes from the Derby library appear completely unrecorded and undocumented before 1842, when acquired by Derby from Lambert's estate.

The drawings, bold and striking examples of Australian birds, plants, fish, a handful of mammals and a single scene, that in 1788, with the arrival of the First Fleet in Sydney Cove, were so strange and wondrous, puzzling and new they seemed almost the stuff of fairy tales. As responses to those bewildering and captivating first encounters, drawings such as these are like a time capsule that connects us with the unique pre-European natural environment in the Sydney basin.

Because they have only very rarely been consulted during the last century or more, the images are also incredibly fresh and new: there is no fading, little deterioration.

What the Library acquired with this collection is a large piece of a much bigger, 200-year-old natural history puzzle that tells us so much about the value and the uses of drawings, about the fascination that the British felt for the natural world they found in NSW in 1788, and about responses to the new and the unfamiliar, to a world in which "nature was reversed".

A few story threads started to emerge.

Copying

Copying has become a central part of the story of drawing and art practice in the colony: copying was a valid way of circulating drawings, a way of responding to the fascination of the new, of feeding the appetite of people like Sir Joseph Banks and their extensive like-minded networks, to possess their own drawings, to assist their publishing ambitions, to fill in gaps in their knowledge.

Quite the extent of the copying that took place in London and particularly in Sydney Cove had not been fully appreciated. In particular the extent to which artists in NSW were working together or in reference to each other. It quickly became apparent that the same images appear, again and again, re-used by different artists, and now part of different collections in different institutions and different countries.

Which set of drawings might be the originals is unknown, or perhaps no longer knowable. The quality and style of the known sets of early NSW drawings are variable but there are clues to a possible genealogy, to a possible primacy, of which image might be the source for others.

The Derby collection includes a single scene of Norfolk Island (Illus. 5) which is, in fact, a copy of two drawings, one by Raper and the other unsigned, showing the wrecking of the *Sirius* off Norfolk Island (Illus. 6, 7). Which drawing came first? Did one person record the events in a drawing, and the other make a copy? Or have they been created by two separate witnesses to the same events, working from the same viewpoint? One was George Raper, who we know was a witness to the wrecking. We don't yet know who drew the other.

5: "A View of the West side of Norfolk Island taken from the west side of Turtle Bay," ca 1797/ artist unknown. Watercolour (Derby Collection ML PXD 1098, vol. 1 FL357843. Mitchell Library, State Library of NSW)

6: "The Melancholy Loss of His Majesty's Ship Sirius, Wreck'd on Norfolk Island, on Friday Noon March 19th 1790,"/George Raper. Watercolour (Raper Collection, drawing no. 23. Natural History Museum, London)

Stripped bare of the desperation of the wrecking, the people and the desperate activity — everything that made the original drawings genuine and dramatic — the copy

7: "A View of the West side of Norfolk Island and the manner in which the crew and provisions were saved out of His Majesty's Ship the Sirius, taken from the West side of Turtle Bay after she was wreck'd," ca 1790/Port Jackson Painter. Watercolour (Watling Collection drawing no. 22. Natural History Museum, London)

is a bland and uninteresting drawing. The drama and detail of what is actually unfolding and what the loss of the *Sirius* meant for the colony, were unimportant to a copyist in a London drawing room.

But how do you determine the genealogy, or primacy of drawings?

Determining Primacy

First, the contents of the many collections — around 2,000 watercolours that originated from the first decade of European settlement in Australia — were crosswalked to each other. The lack of provenance, and the absence of signatures or dates mean though that one needs to look for other clues to understand a possible genealogy of the drawings.

Pentimenti, those changes or adjustments made in a drawing, can often indicate primacy. An artist creating a work may reposition the subject of a drawing either to improve or correct it. These changes are not always evident in subsequent copies but as in the drawing of a Masked Lapwing from the Derby Collection, the lead in the white paint used at the time to obscure a correction

8: Masked lapwing or Spur winged plover (*Vanellus miles*), 1790s/artist unknown. Watercolour (Derby Collection ML PXD 1098, vol. 4 FL345345. Mitchell Library, State Library of NSW)

9: Detail of Masked lapwing or Spur winged plover (*Vanellus miles*), 1790s/artist unknown. Watercolour (Derby Collection ML PXD 1098, vol. 4 FL345345. Mitchell Library, State Library of NSW)

has discoloured to black over time, revealing the alteration quite clearly to the naked eye (Illus. 8, 9).

Usually, more detail is included in the original work and some of this detail is lost each time a drawing is copied. Or it could be embellished.

Copying is a fairly loaded word in the art world these days. Copying in the context of colonial drawings did not mean creating identical drawings. And it did not mean forgeries.

It meant there was a strong correlation, a conformity between some or all of the elements in a drawing. Drawings might easily be compositionally different but still be copies. A copyist might break down elements of an image and create several drawings to reflect the various elements in the original. Or the reverse: several smaller drawings might be copied and combined into a single work. Copies might incorporate all elements of a drawing or select only some components.

Artists might repeat elements of each other's drawings, eliminate or substitute components. Detail might be lost in copies. Backgrounds might disappear or reappear elaborated and embellished.

Sometimes, though, even the smallest omission is glaring, important and, at times, inexplicable. The Wattle Bird, drawn by the Sydney Bird Painter, accurately depicts the bird with two wattles, one each side of its head (Illus. 10, 11, 12). Other versions seemingly replicate it perfectly but for one critical detail, the omission of a wattle that is then repeated in the subsequent copy. It is difficult to reconcile the possibility that the correct drawing could be anything other than the original.

10: Red Wattle-Bird (*Anthochæra carunculata*), 1790s/Sydney Bird Painter. Watercolour (ML Safe PXD 226 f. 60 FL8966136. Mitchell Library, State Library of NSW)

11: "Wattled Bee-eater" *(Anthochæra carunculata)*, 1788–1793/Port Jackson Painter. Watercolour (Watling Collection, Natural History Museum, London Watling drawing — no. 166)

12: "Wattled Bee-eater," ca 1797/artist unknown. Watercolour (Derby Collection ML SAFE PXD 1098 vol. 1 f. 37 FL357938 Mitchell Library, State Library of NSW)

This copying also suggests that artists were working together or in reference to each other, and, more than that, suggests the possibility that they were sharing drawings, and copying each other's work in little de facto drawing schools.

Who were the Artists?

Who were the artists? We still can't put names to drawings in many, many cases but we can often identify categories of artist.

The quality of drawings by convict artists is often variable. Some are poorly executed. Others show the style traits of allied trades or professions such as the more decorative techniques of ceramics painting which are typically characterised by more dispersed arrangements of flowers and leaves, hinting at previous occupations of convict artists (Illus. 13). Convict artists included obvious professional artists, such as Thomas Watling.

13: Christmas Bush (*Ceratopetalum gummiferum*), 1788–1794/artist unknown Watercolour (DGD 38 f. 1 FL1000688 Dixson Galleries, State Library of NSW)

14: "Taking of Colbee & Benalon. 25 Novr 1789"/William Bradley. Watercolour (ML safe 1/14 FL1113938 Mitchell Library, State Library of NSW)

Surgeons, such as Arthur Bowes Smyth, were often amateur artists with an interest in recording the medicinal properties of plants, and drawing was also part of a suite of compulsory skills required for progression though the ranks of the Royal Navy, needed to record the coastal profiles and features of places passed, named or claimed.

Naval art training was certainly basic in comparison with, for example, training received at the Royal Academy of Arts. Copying the work of others to learn and improve was part of a long tradition of art training, which mostly began with copying, the purpose precisely to practise, refine and perfect technical conventions and methods. Copying was a bread-and-butter skill in the art world more generally.

A style of sorts emerged to meet naval requirements. Naval drawings often feature precise frame lines usually in-filled with beige or pink watercolour inside heavy black lines (Illus. 14). The inclusion of scales of feet was also common.

Yet drawings with naval origins are perhaps easier to recognise by omission, by what was seemingly not taught rather than what was. Life drawing, for example, was not in the curriculum of the Royal Navy and those officers who did venture into this area show little skill or aptitude for it. There is little evidence that naval artists learned and honed the technical conventions of representing perspective or scale.

More often than not it seems engravings and prints, rather than paintings, were used to copy for practice, and the effect of this can be seen in many drawings that originated in NSW.

Shading, volume and tone in engravings are built up through the use of spaced, tapering lines, or by cross hatching. The effect of this can be seen in naval drawings which often replicate the effect of engraving lines rather than the more painterly technique of blend-

15: Detail of Illus. 2 above

16: Little Grebe (*Podiceps ruficollis*), 1790s/ Sydney Bird Painter. Watercolour. (ML SAFE PXD 226 no. 95 FL8966171 Mitchell Library, State Library of NSW)

ing colour with a brush (Illus. 15). Blending can be seen in the work of more skilled artists such as the Sydney Bird Painter, suggesting the possibility that this talented but unidentified artist was not a naval artist (Illus. 16).

The Use of Gold Leaf in the Drawings

The Sydney Bird Painter's drawings are in a volume of a hundred drawings that came into the collection of the State Library of NSW in 1902. Its provenance is completely unrecorded and for the last three decades it has been believed to have been drawn in

17: Norfolk Island Pigeon (*Hemiphaga novæseelandiæ spadicea*), 1790s/Sydney Bird Painter. Watercolour with gold leaf on head and throat (ML PXD 226 f. 84 FL8966160 Mitchell Library, State Library of NSW) [now extinct — Ed.]

India because of the extensive and expert use of gold leaf (Illus. 17).

Analysis of the materials used in colonial drawings, and technical knowledge of early colonial drawings, goes to the heart of the many mysteries and confusion which surround the history of early colonial art in Australia. This is an area which is surprisingly little understood and traditional connoisseurship has not resolved the ambiguities. One of the few remaining opportunities for further exploration and comparison has been technical observation and analysis.

One of the unexpected features of early colonial drawings from this period is the inclusion of metallic leaf — gold, silver and alloy — in a surprisingly high number of drawings of NSW subjects.

In the absence of provenance information, it has simply been presumed that these drawings, while they might be of a NSW subject, could not possibly have been created in NSW, not only because of the lack of skill required to apply gold leaf but also because the availability of gold in the early settlement in Australia was considered to be so unlikely as to be impossible.

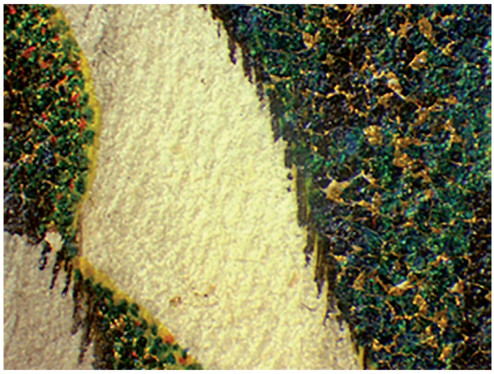
Yet X-ray fluorescence analysis showed the metals observed in early NSW colonial drawings not only looked like gold, they were in fact either gold leaf of a surprisingly high purity, or silver, or Dutch metal, used as a gold substitute in cheaper jewellery.

The surprise is that the presence of gold leaf and other metallic leaf is in fact quite so widespread in natural history drawings of NSW subjects, and that it has been so skilfully applied, used to create iridescent effects in the wings, eyes, heads and throats of birds, or the sheen in fish.

The idea that gold and silver leaf, and the expertise to apply it would have been available in NSW seems unlikely.

Yet the technique of laying down gold leaf and layering it with watercolour to imitate the appearance of gold shimmering through the paint was well known, the materials were available well before the First Fleet sailed from England in 1787 (Illus. 18). Naval officers often supplied their own art materials. George Raper's will included the dispersal of his art materials after his death.

There is also an intriguing reference, in the journal kept by First Fleet surgeon Arthur Bowes Smyth, where he refers to some of the officers giving red cloth and gold foil to the Aborigines which they twisted into their hair (Bowes Smyth, ML Safe 1/15).[2] Gold foil is thicker than very fine gold leaf, thick enough to support its own weight and be twisted, as Bowes Smyth described. Gold leaf, as can be seen in drawings, is created by



18: Detail from Sydney Bird Painter, showing gold leaf. Micrographic photograph by Kate Hughes (ML SAFE PXD 226 Mitchell Library, State Library of NSW)

gently beating the thicker foil to something that is less than wafer thin.

The presence of gold leaf certainly marks these drawings out as something to be valued, something that was considered to be important. Their use is a clear sign of the value placed on NSW drawings.

Sydney Countrysides, and Watermarks

Volume 4 of the Derby Collection is one of those previously unrecorded volumes, thought at the time of acquisition in 2011 to have been drawings created in England rather than NSW.

The volume is distinguished by drawings of giant birds in Lilliputian landscapes thought to represent the English countryside (Illus. 19). The park-like qualities depicted in the drawings accord with the frequent comments of the British that the land around Sydney and inland reminded them of parks with tracks winding through them. We have, wrote surgeon George Worgan, "a great extent of parklike Country … with extraordinarily luxuriant

[2] Bowes Smyth, ML Safe 1/15)

19: Hawkesbury duck or Australasian shoveler (*Anas rhynchotis),* 1790s?/artist unknown. Watercolour (Derby Collection ML SAFE PXD 1098 vol. 4 FL345396 Mitchell Library, State Library of NSW)

20: "J Whatman 1794" watermark. (Photograph by Kate Hughes)

grass."[3] John Hunter described "the Woods here … resemble Deer parks, as much as if they were intended for that purpose,"[4] and Arthur Phillip noted that the grass is "as fine as in any Park in England."[5]

These estate-like effects are now understood to have resulted from the systematic management of the land by Aboriginal people who regularly burned the growth and created grasslands and networks of tracks.[6]

So, could these drawings have originated in NSW rather than England?

We looked systematically at the papers used and their watermarks. The interest was not so much in the dating of watermarks, though that's also interesting. The evidence of dated watermarks can only ever be indicative of the genealogy of drawings rather than conclusive: they give a not-before date, but not an end date, for the creation of drawings. Here the interest was more in what the actual designs might tell us.

Watermarks, the faint manufacturer's design that can be seen in paper when held up to light, are unique to each mill (Illus. 20). Handmade from wire and incorporated into the framed moulding that holds the pulp used to make an individual sheet of paper, watermarks leave a design mark in the finished paper. Because they're handmade, even within a single paper mill, each watermark from each moulding will be unique. So exactly matching watermarks tell us that the papers were formed in the same paper mould.

Across collections of drawings of NSW subjects we have now found papers that have been created not only in the same paper mill but in the exact same paper mould, including drawings in Volume 4 of the Derby Collection thought at the time of acquisition to have been created in England but now reconsidered as possibly, even probably, created in NSW.

Paper supplies were limited in NSW and were replenished only as ships arrived, so there is a strong possibility that previously unrelated watercolour drawings on paper bearing exactly matching watermarks could in fact have been created if not simultaneously, then within a limited timeframe using the same limited stock of paper.

[3] Worgan, ML Safe 1/114

[4] Hunter, Safe DL MS 164

[5] Phillip to Banks, ML/DL Series 37.08

[6] See the discussion of fire-stick farming in Gammage (2012). [Ed.]

Watermark analysis of drawings of NSW subjects has strengthened the argument that unprovenanced drawings, previously dismissed as non-colonial in origin and long thought to have been created in England or even India because they were so skilful and because they used gold leaf, were drawn in the colony, helping to establish the history and context of the collections.

Conclusions

So we are pulling together dispersed sets of drawings that can now be sourced to NSW at the time of their creation, linking together for the first time works not previously connected.

And so, in such a small community as Sydney Cove, it becomes easy to imagine that drawings might have been circulated and shared, repeated, honed, refined and copied in much the same way as stories and gossip. Research based on letters and diaries from the colony as well as auction sale records describing the dispersal of collections brought back to England from NSW has now been added to rich data derived from technical observation and analysis.

Comparing the many related sets of drawings from the early colonial period has provided evidence that helps determine the history and chronology of these foundation Australian drawings, to understand how, and where, they were created, using science and observation to advance art historical information.

Responding to and investigating the drawings as primary evidence of colonial art practice also alerted us to the precariousness of thinking that we know history, that we know what happened and have all the information. These collections raised questions we had not previously thought to ask; they suggest possibilities we had not considered.

What became clear was that, from the very beginning of European colonisation in Australia, far more people were drawing and describing what they were seeing and experiencing and recording life in NSW than we can yet put names and faces to. Cultural activities, writing extended accounts, recording impressions in letters and journals, drawing what they saw and did, not only found a foothold in the struggling colony, they flourished. We realise that from the very earliest days of the settlement, against terrible odds and great physical and psychological hardship, in a place of punishment and with so much uncertainty, there was also space for creative responses.

Looking at the collections of drawings anew has opened new patterns to understand other possible histories. They engage with, even challenge, some of the mythology about the early European past in Australia. They question where our perceptions and ideas have come from, and they expose new and different sources of information, creating different perspectives on past experience.

The emergence of the Derby Collection of drawings prompted new, detailed art historical analysis of the traditions of botanical art production and its convention of copying and dissemination. Importantly, the Collection helps demonstrate that the colonisation of Australia was not just physical and cultural occupation of the land but intellectual engagement with it.

To repeat, the impression remains of a nation built on near starvation, suffering, floggings and hangings, and a sense of utter futility. And, to an extent, that is certainly true, but survival was not just a matter of food and shelter, it was also very much psychological.

Importantly, these collections present a view of the early settlement as a culturally richer, more expressive community than commonly thought, expose new lines of investigation and encourage us to look more deeply at our history through the prism of collections. They are evidence of a healthy engagement, for many, with unfamiliar and challenging surroundings.

They exist, in part, as a tribute to our incessant inquisitiveness about what lies outside our reach, what is beyond our current knowledge and comprehension, and the compulsion to try to make sense of it. They signal the enduring nature of human vitality and curiosity, of the need to push boundaries and explore, and to try to understand the world and our place in it.

All this is not to suggest that the colony wasn't patriarchal, authoritarian and controlling. It was principally a place of punishment. But in spite of this there were people who saw an opportunity, who were intrigued, even enchanted, by what they found.

Through drawings it becomes possible to imagine the natural world of the Sydney basin in 1788; to demonstrate that the convict colony at NSW was a far more active and expressive cultural community than commonly thought. This has the potential to change perceptions of Australia as a nation.

Collections such as these have the capacity to shake up and challenge the stories we tell about the foundations of British colonisation in Australia. They are a powerful reminder of how our collections both reflect and inform, but also obscure, our understanding of history and ourselves.

They are direct evidence that in late 18th century NSW more people than we can yet identify and name found ways to rise above the isolation, despair and hardship of a remote penal colony, and to retain a sense of humanity and connectedness with each other, and with home.

They laid the foundation for ways of responding to the land as awe-inspiring or alienating, as endless resource or precious heritage, as *terra nullius* or a land that had been actively managed for millennia, dichotomies that still challenge Australia today.

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Speed limit: how the search for an absolute frame of reference in the Universe led to Einstein's equation $E = mc^2$ — a history of measurements of the speed of light

John C. H. Spence ForMemRS

Department of Physics, Arizona State University, Tempe AZ, USA

E-mail: spence@asu.edu

Abstract

This article describes one of the greatest intellectual adventures in the history of mankind — the history of measurements of the speed of light and their interpretation (Spence 2019). This led to Einstein's theory of relativity in 1905 and its most important consequence, the idea that matter is a form of energy. His equation $E=mc^2$ describes the energy release in the nuclear reactions which power our sun, the stars, nuclear weapons and nuclear power stations. The article is about the extraordinarily improbable connection between the search for an absolute frame of reference in the Universe (the Aether, against which to measure the speed of light), and Einstein's most famous equation.

Introduction

In 1900, the field of physics was in turmoil. Despite the triumphs of Newton's laws of mechanics, despite Maxwell's great equations leading to the discovery of radio and Boltzmann's work on the foundations of statistical mechanics, Lord Kelvin's talk[1] at the Royal Institution in London on Friday, April 27th 1900, was titled "Nineteenth-century clouds over the dynamical theory of heat and light." In it, he cited the recent failed attempts by Michelson and Morley to detect the Aether, and the black-body radiation problem as the two great unsolved problem of physics. The Aether was a ghostly invisible vortex foam believed to fill all space and to provide an absolute stationary reference frame, through which the Earth was speeding along at about 70,000 mph around the Sun, creating an "Aether wind" on Earth. Maxwell had successfully used this concept of the Aether to derive his equations, with light travelling at a fixed speed with respect to the Aether frame of reference. If we consider waves running along a river in which there is a current, it was understood that the waves "pick up" the speed of the current. But Michelson in 1887 could find no effect of the passing Aether wind on his very accurate measurements of the speed of light, no matter in which direction he measured it, with headwind or tailwind. This could not be reconciled with Maxwell's work, which treated the Aether as a fixed frame of reference. Only Einstein was to clarify all of this in one of his great papers of 1905, by introducing his theory of relativity, and later that year the mass–energy equation which it predicted.

The solution of the first problem identified by Kelvin led to Einstein's relativity in 1905; the solution of the second led to the birth of quantum mechanics. By this time the ageing Kelvin had become very opinionated. Like Max Planck, he had worked on the problem of the energy balance between light emitters and absorbers in black-body

[1] Kelvin (1901).

radiation. He was well known not to be a good listener, unlike the great physicists Rayleigh and Stokes. J.J. Thomson, the discoverer of the electron in 1897, said of him, in this regard, that "he was a counter-example to the idea that a good emitter is a good absorber."

Author's Note: In view of the technical sophistication of many of the ideas, the difficulty of seeing things through the eyes of a mediæval philosopher and mystic such as Kepler, for example, and the subtlety of historical context (our view of the past depends on the present) I've tried to emphasize the underlying concepts and personalities instead, and to explain them in clear simple language, perhaps to the point of oversimplification. Much fuller historical detail, context, interpretation and mathematical analysis can be found in the extensive list of references, particularly in the texts by Whittaker (1910),[2] Darrigol (2000),[3] Hunt (1994),[4] Weinberg (2015)[5] and Filonovich (1986),[6] and other professional historians of science. The books by Richard Holmes (2008), Richard Rhodes (1986), and Malcolm Longair (2003)[7] are particularly recommended.

[2] Whittaker is comprehensive, advanced and authoritative, with full mathematical analysis in modern notation. British emphasis, and later editions with important changes.

[3] A comprehensive, modern historical view, providing depth and insight. Equations in all four systems of units, and relationship between them.

[4] An excellent account of those who came after Maxwell (Lodge, FitzGerald, Heaviside, Hertz, Larmor) and their contributions as founders of modern classical electrodynamics.

[5] An excellent survey of the history of astronomy from the Greeks to the time of Newton, with simple mathematical derivations in appendices.

[6] An excellent short account of the topic of this article, with simple equations.

The speed of light before Rømer

Two great questions have perplexed scientists from the time of the ancient Greeks: how can light reach us from the distant stars across the vastness of empty space — what medium supports the light waves or particles in a vacuum? — and at what speed does it travel — is it instantaneous, as most believed, or does it take time, as the Greek philosopher Acragas (BC 490–435) believed, so that when we look at the stars we are looking back in time? In addition to his great book *Elements* on geometry, Euclid had also written a book on *Optics* (Burton 1945), in which he suggested that vision was based on rays ("visual fire") shooting out from the eye at the things we look at, and in this way was able to explain changes in perspective. (In fact the eye receives light from the sun reflected from objects). Euclid avoids trying to explain why we cannot see at night. Galileo, in a book published in 1638, speculates on the speed of light, proposing experiments using people on mountain tops signalling to each other with shuttered lanterns to measure the speed of light. Since that speed is about 186,000 miles per second, this could never have worked, but it was actually tried experimentally in 1667 by the Florentine Academy.

Studies by Fermat and Descartes in 1637 of the phenomenon of refraction, the bending of light rays entering a new medium, were based on the concept of a refractive index, the ratio of the speed of light in vacuum to that in the medium, using Snell's

[7] A superb account of the history of fundamental theoretical concepts in physics, together with all equations in consistent modern form.

law.[8] This work, and that of Christiaan Huygens in his 1679 book *Traité de la Lumière* left the community of scientists divided for more than a century into two groups. There were those ("corpusculists") who believed that light was a stream of particles which sped up on entering a denser medium, and those ("undulationists"), like Huygens, who believed it was a wave which slowed down. The modern view is that light travels as a wave and arrives as a particle.

None of this answered the old question of what medium supports starlight in the vacuum of outer space, as air does for soundwaves. It was known that the speed of sound waves is given by the square root of the elastic modulus (Young's Modulus,[9] a measure of the stiffness of a material) divided by the square root of its density. For the enormous speed of light, one had to assume that the Aether (filling the vacuum of outer space) had a density similar to steel, but was also 3600 million times stiffer than steel. At the same time, it must not impede the motion of the planets, and it must be invisible, and permeate all forms of matter. Yet physicists clung to this notion of an Aether well into the twentieth century — it is fair to say that no physicist born before about 1900 (including Michelson himself, and even Lorentz, whom we will meet later in this essay) would say with certainty that it did not exist.

Ole Rømer

In 1676 the Danish scientist Ole Rømer was the first to make a reasonably accurate measurement which gave the speed of light, in one of the greatest experiments in the history of physics (Cohen 1940). But the story starts earlier, in 1598, when Ferdinand II, the King of Spain, established a prize for the determination of longitude. This is the distance, for example, which a ship might travel around the equator. By keeping the noon-day sun overhead (or the Pole Star in the same position at night) they could be sure they were sailing along the equator, that is, at constant latitude. Spain was losing many ships at sea due to poor navigation and piracy, and the military and commercial value of a reliable method of longitude determination was clear. Knowing that ships must stick to the equator to avoid getting lost, pirates could lie in wait anywhere along their path. In 1610, with his newly improved telescope, Galileo had discovered some of the moons of Jupiter, including Io. He realized that the eclipses of Io, as it disappeared behind Jupiter every 42.5 hours could be used as a universal clock (ticking every 42.5 hours) for mankind, since it could be seen from anywhere on Earth. So by using these eclipses to keep track of time at home in Spain while sailing around the world, and using the maximum height of the Sun each day to determine local noon, it would be possible to measure the time-difference between home and one's current location. This time difference, as we all know from international air travel, can tell us how far around the world we have travelled. A twelve-hour time difference takes us halfway around the planet.

Galileo's method was fine, and has been used on land for centuries since, but he did not win the prize because the ships rocked too much to allow accurate sightings of the eclipses of Io through a telescope. (Harrison's chronometer, with its torsion pendulum immune to the rocking of ships, did not appear until 1761.) In 1671, Cassini, the

[8] On refraction. See https://en.wikipedia.org/wiki/Snell%27s_law [Ed.]

[9] See https://en.wikipedia.org/wiki/Young%27s_modulus [Ed.]

head of the Paris Observatory (still standing today) decided to test Galileo's method by measuring the longitude difference between Paris (longitude zero) and one of the few places whose longitude was known. This was Tycho Brahe's old observatory at Uraniborg (now a Brahe museum) on the island of Hven near Copenhagen. Cassini asked his colleague Professor Bartholin at Copenhagen to do this, and Bartholin took along his graduate student Ole Rømer, shown in **Figure 1**. Bartholin, a mathematician, later became famous for his discovery of birefringence. The group made many observations of Io at recorded times before Rømer took the observations back to Paris for analysis. They had found that the time difference between when the Sun was directly overhead in Paris and in Uraniborg was about forty-two minutes, due to the rotation of the Earth. If Uraniborg had been due west of Paris on the equator (it isn't), then the ratio of forty-two minutes to twenty-four hours

Figure 1. Ole Rømer. (From Google Images.)

should be equal to the distance between Paris and Uraniborg divided by the circumference of the Earth.

But Rømer noticed that some of the Io eclipses were up to ten minutes late. He attributed this to the fact that light travels with a finite speed. This was a remarkably bold assumption at the time for a very young scientist. The situation is shown in **Figure 2**, in the original figure published by Rømer in 1676 in his paper, which eventually appeared in English in the *Philosophical Transactions of the Royal Society*. If the Earth were stationary at L (or moving near H), an observer on the Earth would measure a time interval of 42.5 hours between eclipses, the times at which Io (moving anticlockwise) first appears from behind Jupiter at D. But if the Earth moves from L to K while Io is performing its orbit, the measured time between eclipses will be longer by the time it takes light to travel from L to K to catch up with the Earth. The Earth moves at about 30 Km per second or 18.6 miles per second relative to the Sun, and so moves about 2.8 million miles between eclipses. On the other hand, if, six months later, the time between eclipses is measured while the Earth is moving toward G in an anticlockwise direction, light will have less distance to travel and this time will be shorter. This was Rømer's explanation for the variations in orbital periods of Io found among many observations at Uraniborg. His explanation gave the strongest evidence to date that light does not travel instantaneously, and if the diameter of the Earth's orbit around the Sun were known, and hence the Earth's speed, it could be used to estimate the speed of light with reasonable accuracy for the first time.

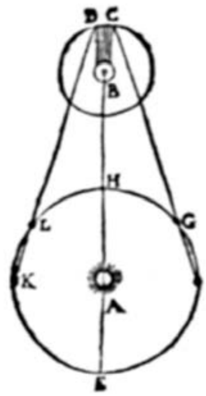

Figure 2. Rømer's original diagram (1676). The Sun at A, orbited by the Earth at K with Jupiter at B and its moon Io at C. (From Cohen 1942.)

Rømer made a prediction in September 1678 at an address to the Académie des Sciences in Paris that the November 9 eclipse of Io would be late by ten minutes. He added that he could further estimate that it would take light eleven minutes to travel from the Sun to Earth (the modern value is eight minutes and nineteen seconds). The confirmation of this prediction brought him immediate recognition and established his reputation as a scientist. The delay was important, since it would lead to errors in navigation. By using the best estimate then available for the distance between Earth and Sun (one Astronomical Unit, or AU), and knowing the Earth's period of a year, and hence its speed, one could then also estimate the speed of light. The best estimate of one AU, due to Cassini, had been obtained by the highly inaccurate method of parallax, and was rather fortuitously only in error by about 6%. In fact it was Christiaan Huygens who, in 1690, first used Rømer's time delay measurement to get a speed for light, which was within 15% of the modern value.

Newton (who met Rømer during his visit to England in 1679) duly took note of all this, and we can compare Newton's "action at a distance" theory of gravity, which assumed (incorrectly) that gravitational forces act instantaneously across the Universe, with his acceptance of a finite speed for light. Newton's ideas on gravity owed much to Robert Hooke. Since Kepler's laws (Love 2015), which provided a simple relationship between the period of a planet and the radius of its orbit, were well known at this time, the approximate radii of all the planetary orbits could be found from their known periods once that of one (the Earth) had been found.

Rømer, a Protestant in Catholic France, eventually had to leave Paris due to prejudice against his religion. He became Professor of Mathematics at Copenhagen University and Astronomer Royal. There were many notable achievements in his later career, including his appointment as Chief Justice of the Supreme Court of Copenhagen, Mayor of Copenhagen, and his reform of the tax system. In science he invented the epicycloid gear shape for reducing gear friction, and devised the modern two-point "Fahrenheit" temperature scale, essentially inventing the thermometer. He was unlucky in that practically all of his observations were destroyed in a fire at his observatory in 1728, but some were rescued by his devoted assistant Peder Horrebow, as vividly described in his book (still in print, in Latin (Horrebow 1735)). Rømer also sent observations to friends, which have survived, and maintained a "commonplace book" for notes, entitled *Adversaria*, which he kept by his window at the library of the University of Copenhagen. Remarkably, this book was discovered, still there, early in the last century, and has since been published. A modest and generous man, he died in 1710. **Figure 3** shows him at work in his observatory.

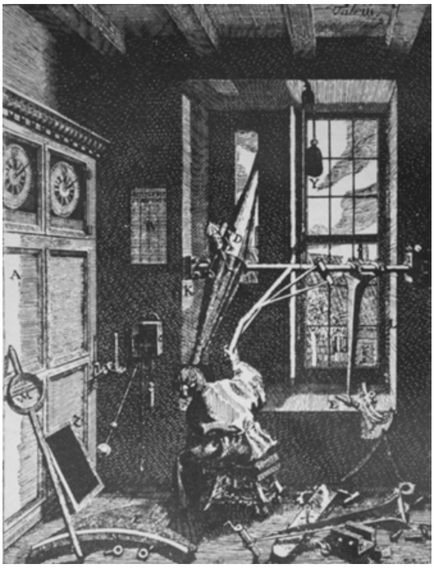

Figure 3. Rømer's transit telescope. Note pendulum clock and counterweights. (From Horrebow 1735.)

Measuring the cosmos

Rømer had measured a time delay, and to convert this to the speed of light he needed accurate distance measurements. The Greek astronomer Eratosthenes (BC 276–194) had used measurements of the length of the shadow of a stick at the same time in two cities to give an estimate of the size of the Earth within 15% of the correct value. The Greek's estimate of the Sun–Earth distance (actually about 93,000,000 miles), although based on sound trigonometric principles (such as the right-angle triangle which occurs at half-moon) were at least twenty times too small, since they had no method for measuring angles accurately (Weinberg 2015). Astronomers became obsessed with determining the path and predicting the motions of the planets, and measuring the distances to the Sun, planets and stars. For a simple mathematical description of the methods used by early astronomers such as Ptolemy, Copernicus and Kepler (the first to show that planets moved in an elliptical orbit), see Hoyle (1973). The parallax method for measuring distances is shown in **Figure 4**. But for the nearest star, this angle is equivalent to observing a one-inch diameter disk at a distance of 4.2 miles. A telescope was clearly needed. It was not until 1838 that Bessel provided an accurate measurement to a nearby star using parallax.

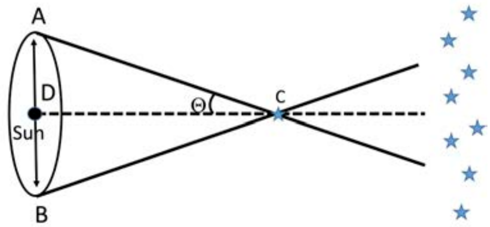

Figure 4. The principle of parallax used to measure stellar distances from Earth. The Earth orbits the Sun around the circle AB with diameter D. A planet is shown at C against a background of fixed stars at right. A different group of background stars will be seen behind the planet if we observe first from A, then six months later from B. This allows angle Θ to be measured. If the baseline AB is known, the distance DC can be found by trigonometry. The diameter of the Earth can also be used as a baseline.

But for the Earth–Sun distance (one AU), the most important improvement on Cassini's value came with the Transit of Venus expeditions during the eighteenth century (Wulf 2012). **Figure 5** (left-hand figure) shows an amateur astronomer's photograph taken in Melbourne of the 2012 transit, when Venus passed across a line drawn from the Earth to the Sun, so that its shadow is seen as a black dot crossing the Sun's bright disk. Using a lens (or a pin-hole) in the window facing the Sun, this image of the Sun can be projected onto an opposite wall in a dark room, and the motion of Venus traced out as it crosses the Sun over a period of hours, the time being noted. Jeremiah Horrocks, who died at the age of 22, did exactly that in 1639 from a house (still standing) near Preston in the UK, and from this observation obtained a value of the Earth–Sun distance of about 60 million miles (Aughton 2004). But predicting when these transits would occur, and the times and places on Earth from which they could be seen, was no easy task. Kepler (1571–1630) had made approximate predictions, and James Gregory in 1663 had shown how the Earth–Sun distance could be obtained from a similar transit of Mercury. The Venus transits occur in pairs eight years apart about once a century.

Figure 5. At left, amateur astronomer's photograph of the 2012 Transit of Venus. Taken in Melbourne Australia using 300 mm lens on June 6 2012 between 9.45 am and 10.45 am. Nikon D7000 camera with adjustable neutral density filter to attenuate the sun's light, fast shutter speed, small aperture. ISO 100. Venus (the black dot near the bottom) is shown crossing the sun's disk. At right, Venus (bright dot) is photographed near the Moon. (Author's copy.)

With the advent of Newton's theory of elliptical planetary orbits (consistent with Kepler's laws), more accurate predictions became possible, and it was Edmund Halley (1656–1742) who predicted the transits of 1761 and 1769, suggesting their use to determine the Astronomical Unit (AU). Halley, who died before it could be done, was a colleague of Newton, Hooke and Wren around the time of the founding of the Royal Society in London. The method proposed by Halley and Gregory is similar (but more complicated) than that shown in Figure 4, but now using the width of the Earth as a baseline. Observations of the transit from opposite sides of the Earth at the same moment will show Venus projected onto a different point on the Sun's disk in the shadow images. If many such observations are made across the Earth at known times, simple Euclidean geometry together with Kepler's laws will show that the distances between Earth and Sun (and to Venus) can then be found, given the diameter of the Earth, the latitude and longitude of the observations, and their local time. Telescopes and pendulum clocks were therefore the equipment taken by astronomers to all corners of the Earth in this first international scientific collaboration in 1761, organized by the Académie Française in Paris, resulting in tracings of the images of the transit drawn on paper. Many disasters attended this first attempt, from disease (dysentery), bad weather, war (between the French and British), piracy, inaccurate longitude determination, and perhaps a cloudy sky at the time of the transit, or a transit which occurred just before sunrise.

Much was learnt from these problems, and national rivalry became a spur to greater efforts for the second transit in 1769. The collaboration was organized by the Royal Society and strongly supported by George II, Catherine the Great, the Académie Française, Benjamin Franklin, and including James Cook. About 250 astronomers contributed from many nations at 130 locations. Points of observation included Baja California (in Mexico, south of Phoenix, Arizona) and Tahiti (by Cook), the selection depending partly on the need to use locations of known longitude and good transit visibility.

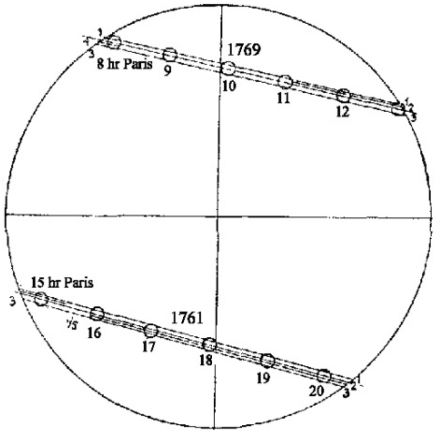

Figure 6. A summary of the observations of the 1761 and 1769 Transit of Venus observations across the sun's disk, as seen from different locations and times on earth. The Venus parallax angle (akin to angle Θ in Figure 4) is, for example, the angle between lines 1 and 3 measured down the page, based on the known angular diameter of the sun. The uppermost line across from the 1769 observations was observed from Tahiti, a lower one from Paris. (From European Southern Observatory web page, Transit of Venus.)

Figure 6 shows the published results, giving the tracks of Venus's shadow across the Sun for both expeditions. The final publication and analysis of all the results in *Philosophical Transactions* in 1771 gave a distance of 93,726,900 miles for the Earth–Sun distance, differing by less than one percent from the modern value. This was a great triumph for international collaboration and the science of the enlightenment: the President of the Royal Society, Joseph Banks, commented that "The science of two nations may be at peace, while their politics are at war."

We have detailed records of Cook's role in all this, as part of his voyage of exploration to Australia in *Endeavour*, with 94 men and 8,000 pounds of sauerkraut against scurvy (Beaglehole 1968). Cook was given written instructions to respect any native peoples, since "no European nation has any right to occupy any part of their country," and to explore the "unknown land of the South, Terra Australis Incognito." He chose the island of Tahiti at Point Venus, the name it has retained, on which to set up his telescopes and clocks in 1769, one of the few places in the Pacific ocean whose latitude and longitude were accurately known, as shown in **Figure 7**.

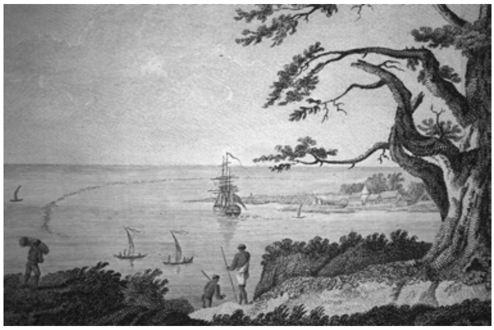

Figure 7. Cook's Endeavour at Fort Venus, Matavai Bay, Tahiti, for Transit of Venus observations in 1769. (Author's copy.)

As Cook wrote in his diary:

> This day prov'd as favourable to our purpose as we could wish, not a Clowd was to be seen the whole day and the Air was perfectly clear, so that we had every advantage we could desire in Observing the whole of the passage of the Planet Venus over the Suns disk: we very distinctly saw an Atmosphere or dusky shade round the body of the Planet which very much disturbed the times of the Contacts particularly the two internal ones. Dr. Solander observed as well as Mr. Green and my self, and we differ'd from one another in observing the times of the Contacts much more than could be expected. Mr Greens Telescope and mine were of the same Magnifying power but that of Dr Solander was greater than ours.

After many adventures (Holmes 2008), Cook returned to England and a hero's welcome, with his observations intact and a vast array of new botanical species collected by Banks. The First Fleet colonizing Australia arrived from Britain soon after at Botany Bay in 1788.

The movement of Venus across the Sun darkens the Sun very slightly. Detecting this darkening is one method which is now used in the search for new planets around stars (exoplanets). A dip in a star's brightness is sought as a planet crosses a line from the star to Earth. This is exactly what happens in a Venus transit under much better understood conditions, which can be used to accurately measure and calibrate the effect. Venus darkens our sun to 99.9% of its unobstructed value, showing how difficult is this search for exoplanets.

James Bradley — the aberration of starlight

James Bradley (1693–1762) is crucial to the history of lightspeed measurement because his entirely new astronomical method provided the first experimental evidence in support of Copernicus's theory that the Earth orbited the Sun, and because of the support it provided for Einstein's relativity. Bradley, in his 1729 publication,[10] provided irrefutable evidence for a finite speed for light, while also producing a measurement of the time for light to travel from Sun to Earth within 2% of the modern value (Stewart 1964). The story is told that he had his crucial idea while sailing on the Thames, comparing the direction of the wind with that of a weather vane on his boat when it turned. The vane, which one would think would always be lined up with the constant wind direction, regardless of the direction the boat was headed, seemed to turn with the boat, even when the wind direction was steady, which was hard to understand. For sailors, this relative velocity effect is familiar: the faster you go when windsurfing, the more the wind appears to swing around to come from a more forwardly direction. For Bradley, the wind was akin to light arriving from a distant star, the boat akin to the Earth. This observation explained to him how the apparent direction of starlight[11] could depend on the Earth's velocity across the stream of photons falling on Earth from an overhead star. His work gave much greater confidence and credibility to Rømer's earlier result, at a time when many still believed that light travelled instantaneously, or did not accept the Copernican idea that the Earth orbits the Sun.

Bradley undertook his observations from his house near Kew in London, using a telescope mounted vertically against the internal side of a chimney, so that he could lie in comfort on a couch below it looking upward for observations over many years. He chose a star near the Pole Star and set out to measure parallax, hoping to support the theories of his near-contemporary Newton. But his star appeared to move in a small circle throughout the year, when he compared the direction of the axis of his telescope with that of a plumb bob, which gave the local vertical direction. (Any motion of the plumb bob was damped by immersing the bob in water).

These changes in the direction of the light from a star can also be understood from the way in which we must tilt an umbrella forward, when walking in the rain. The faster we walk, the more tilt is needed. Similarly, a

[10] See https://royalsocietypublishing.org/doi/abs/10.1098/rstl.1727.0064

[11] Its *aberration*.

telescope will need to be pointed ahead of a star to see it, in the direction of the Earth's motion across the starlight. Equivalently, if the telescope is not tilted, the photons entering it will hit the sides of the telescope tube, as the Earth carries the tube forward, before they reach the observer's eye. Bradley could show that the tangent of this tilt angle is $\beta = v/c$, where v is the speed of the Earth, and c the velocity of light, as shown in Resnick (2018). This constant β became of crucial importance in Einstein's theory. His method therefore gave the speed of the Earth's motion around the Sun, given, for example, Huygens' value for the speed of light. Alternatively he could estimate the speed of light using, for example, Cassini's value for the Earth–Sun distance to obtain the speed of the Earth in orbit. His work was also important for the debate concerning the existence of the Aether, supposedly at rest in the Universe and supporting the propagation of light waves. One resolution to the paradoxes confronting physics in 1900 was the "complete Aether drag" idea that the Aether was fixed to the Earth, rotating with it, a most unlikely scenario. In that event, no tilt of Bradley's telescope would be needed, since the lightwaves are fixed to the Aether. Bradley's careful systematic work over many years was a major contribution to the development of quantitative methods in astronomy. He had shown that indeed "the Earth moves,"[12] supporting Copernicus, and in contradiction to the Church's teaching at the time of Galileo, even if Einstein was later to show that all motion is relative.

Terrestrial lightspeed measurements

To really pin down the speed of light, by 1800 it had become clear that what was needed was a terrestrial measurement of this speed. In 1833, Professor Charles Wheatstone at King's College London had the idea to measure the speed of electrical pulses (which travel at about the speed of light) running along a long wire, by use of a rotating mirror to image electrical sparks at either end (Keithley 1999). Wheatstone was an early developer of the printing telegraph, and he later consulted with Kelvin on the Atlantic telegraph. He started out making musical instruments[13] and studying acoustics. The "Wheatstone Bridge" for precision electrical measurements which he is mainly remembered for was actually invented by a colleague, Christy, but analyzed and promoted by Wheatstone. He was also responsible for using spectral analysis of electrical sparks to identify elements in the electrodes, the forerunner of spectroscopy. His rotating mirror apparatus remains in the basement museum of King's College. An electrical spark, viewed in a rotating mirror, caused an electrical pulse to travel over a quarter of a mile of wire on a drum, emerging to make another spark, viewed in the same mirror. During the time the pulse travelled down the wire, the mirror had rotated slightly, causing a displacement of the two images of the spark. By measuring this displacement, and knowing the speed of rotation of the mirror, he could calculate the time it took for the electrical pulse to travel a quarter of a mile, and hence the "speed of electricity." The mechanism, which I have studied, is a modified clockwork carriage clock. His 1834 publication gave the speed as 250,000 miles per second, somewhat larger than the speed of light.

[12] Ed.: Galileo is said to have murmured, "E pur si muove" — and it yet moves.

[13] Ed.: Wheatstone invented the Wheatstone English concertina around 1830.

François Arago (1786–1853) first proposed using Wheatstone's method in 1838 to address the questions raised by Descartes' and Fermat's work, by comparing the speed of light in air with that passing through water. His light source was a spark, split into two beams, one passing along a tube of water, and both then reflected by a rotating mirror. If the beam passing through the water slowed down, it would support the wave theory, if it sped up, it would support the particle theory. Arago spent a decade unsuccessfully trying to make this work. Arago, a very liberal republican, himself had a most adventurous life (Lequeux 2016). Educated at the École Polytechnique, the story is told that Napoleon Bonaparte requested in 1803 that all students sign a petition supporting his appointment as Emperor. François refused, to which Napoleon, on noting that he came top of the class responded "One can't send down the top student. If only he'd been at the bottom …" Soon after, Poisson appointed him secretary to the Paris Observatory. With Biot, he was sent to Spain to map out a meridian arc, in order to determine the length of the metre, defined after the French Revolution as one ten-millionth of the distance from the equator to the North Pole. (And also very close to the length of a pendulum with a two-second perio.). Unfortunately his surveying activities were misunderstood by the local population as those of a spy for a French invasion, and the twenty-two year old was imprisoned in the Bellver fortress in 1808. He soon escaped in a fishing boat to Algiers, but was once again captured by pirates and imprisoned at Palamos. After release and further adventures, including a trek along the North African coast from Bougie to Algiers, he reached Paris with his meridian notes intact. He was rewarded by election to the Académie des Sciences, appointed to a chair, and given a residence at the Paris Observatory for life. He was active in the development of photography, the railways and telegraph system, gave public lectures on astronomy for 35 years, and wrote invaluable memoirs of deceased Académie members. It was said of him that his "rapidity and facility of thought, his happy piquancy of style, and his extensive knowledge peculiarly adapted him to the position he was given as perpetual secretary of the Académie in 1830."

With the fall of King Louis-Philip, Arago joined the provisional government in 1848, the "year of revolutions," becoming minister of War and also of Marines and Colonies. In these positions he managed to improve rations and abolish flogging in the navy, and to abolish slavery in the French colonies. He is remembered by street names, schools, an auditorium and statues in Paris.

Arago's student Hippolyte Fizeau (1819–1896) collaborated closely with a colleague Leon Foucault (1819–1868) on many projects at the Paris Observatory, until it dawned on them both that the problems with Arago's apparatus could be addressed by sending the light beam back on itself from a stationary mirror (Tobin 1993). Fizeau, who was more theoretically inclined than Foucault (a superb experimentalist) decided on the scheme shown in **Figure 8** using a rotating toothed wheel, whereas Foucault adopted a rotating mirror, which proved a little more accurate. In Fizeau's scheme (**Figure 8**), light passes through the gap between teeth in a rotating wheel, to be reflected back from a mirror at the far end. By the time light returns, the gap has been replaced by a tooth, and the light (viewed from the side at S) is blocked. The speed of

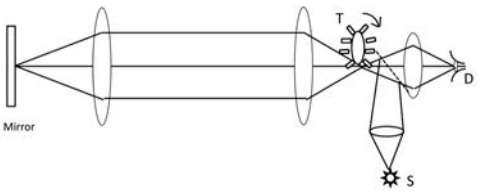

Figure 8. Fizeau's apparatus for measuring the speed of light, showing rotating toothed wheel T, source of light at S and detector at D. The light passes between the teeth, but by the time it comes back from the mirror a tooth has moved around to block it.

the wheel was adjusted until the light could either be seen (through the next gap) or not seen. With the wheel rotating at 1000 revolutions per second, and a thousand teeth on the wheel, he only needed about a thousand feet for the round-trip of the light, travelling at about a foot every nanosecond (10^{-9}s). The source was set up at his father's house in Suresnes, and the mirror 5.4 miles away at Montmatre, so that a speed of only 12 revolutions per second was sufficient. His result, in 1849, for the speed of light, was 3.14×10^8 m/s, against the modern value of 2.99×10^8, an error of about 5%, but only slightly larger than the astronomical measurements of the time. The result won him the Triennial Prize created by Emperor Napoleon III for 30,000 francs, or six times the annual salary of his rival Foucault at the Paris Observatory.

Leon Foucault spent twelve years perfecting his method, shown in **Figure 9**. Light sent from the source S1 via the rotating mirror M1 to the stationary mirror M2 will be reflected back to M1 after it has turned slightly, moving the final image to S2. By plotting the displacement between S1 and S2 against the rotation speed of M1 he obtained a straight line whose gradient gave the speed of light. But this was a particularly ingenious optical arrangement, for if M1 is rotated slowly in a continuous stream of light (so that the finite speed of light does not affect matters at all), the image of S1 reflected back is not displaced at all, regardless of the angle of rotation of the mirror M1. At high rotation speeds, the light is chopped up into pulses by the beam from the rotating mirror scanning across the fixed mirror M2.

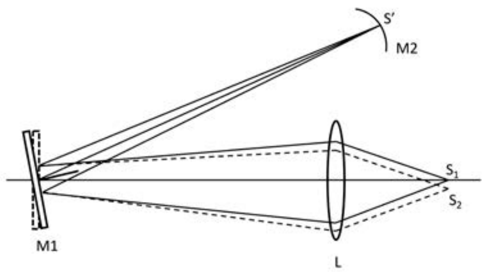

Figure 9. Foucault's rotating mirror system for measuring the speed of light. The mirror M1 rotates continuously about the normal to the page, sweeping the beam across mirror M2.

His mirror (**Figure 10**) was driven by a bellows-powered air-turbine (based on a siren), built for him by his friend Cavaille-Col, who had built the Notre Dame pipe organ. The tone generated by a fast rotating mirror could be compared with a piano, to give the frequency, as Wheatstone had first done, or more accurately using another toothed wheel and a stroboscope. Michelson used a tuning fork. The light source was focused sunlight, using a moving heliostat mirror which compensated for the rotation of the Earth to keep the Sun's focus stationary. The optical path could be folded by additional mirrors, for a total length of 20 metres. His result, published in 1862, was 298,000 ±500 km/s, very close to the value we use today.
Foucault also measured the speed of light in water, resulting in an intense race with Fizeau, who had done the same using his

method. The work was reported in Paris newspapers as "measuring the distance to the sun in the laboratory." Foucault reported his result slightly before Fizeau, and both results supported the (correct) idea that light slows down in water, and is a wave. It was, of course, Foucault, who in 1851 erected the huge pendulum in the dome of the Panthéon in Paris which directly revealed the Earth's rotation (Tobin 1993). This is simply understood if we imagine the pendulum at the North Pole, swinging in a fixed plane (fixed by the starting push, not by any absolute frame of reference) with the Earth rotating below.

Figure 10. Foucault's 1862 rotating mirror (the black disk at center), driven by compressed air from a pipe-organ pump. (From Tobin 1993.)

These rotating mirror measurements were continued with increasing accuracy until the 1920s by Albert Michelson, Marie Cornu and others. Cornu worked through the time of the siege of Paris in 1870 by Bismarck and the Paris Commune, in which Paris was more severely damaged by shelling than at any time before or since, as shown in contemporary photographs. Messages were sent out in balloons and returned by homing pigeons during the siege.

Fresnel, Huygens and Young

Around 1650, Grimaldi, a Jesuit priest, reported the fuzzy shadow edge cast by a sword blade, which was hard to explain if light consisted of small particles travelling in straight lines. Leonardo da Vinci had previously suggested that light was a wave. Alternatively, if light was a wave, like sound, why did it not travel around corners? As evidence for interference effects accumulated, support for a wave theory of light increased steadily throughout the nineteenth century, until one of Einstein's 1905 papers established the modern idea that light travels as a wave, but arrives as a particle. Newton had been ambivalent: his "Newton's rings" (and his explanation for the colours in soap bubbles) supported a wave theory, but most of his writing supported light as a stream of particles. Here is what Newton writes about the wave–particle duality in 1704 in his book *Opticks*:

> If a stone be thrown into stagnating water, the waves excited thereby continue to arise in the place where the stone fell into the water, and are propagated from thence in concentric circles upon the surface of the water to great distances. And the vibrations or tremors excited by vibrations in the air by percussion continue a little time from the place of percussion in concentric spheres to great distances. And in like manner, when a ray of light falls on the surface of any pellucid body and is there refracted or reflected, may not waves of vibration, or tremors, be thereby excited in the refracting or reflecting medium at the point of incidence … and are not these vibrations propagated from the point of incidence to great distances ? And do they not overtake the rays of light, and by overtaking them successively do they not put

them into the fits of easy reflection and easy transmission described above.

The three great champions of the wave theory were Christiaan Huygens (1629–1695), Thomas Young (1773–1829) and Augustin-Jean Fresnel (1788–1827). Huygens was led to his wave theory, perhaps the first, around 1678 from observations of "Newton's cradle" (actually invented by Robert Hooke), a line of steel balls in contact, suspended by strings, as sold now at museum stores. When the first is struck, the last one jumps off the end, while the intermediate balls appear to remain stationary. (In fact, a pulse of elastic energy is transmitted at the speed of sound). He imagined space filled by an Aether consisting of minute hard invisible balls, supporting the pulse propagations of light. Inspired also by observations of ripples in a still pond when a stone is dropped into it, his wavefront construction, showing every point on a wavefront acting as a new source of waves, became one of the most important ideas ever in science. This led to Fresnel's mathematical formulation of near-field light propagation and diffraction in 1818, well before Maxwell's equations for light. The mathematics in Fresnel's 1818 paper is identical to that found in any modern textbook on near-field diffraction. This accounts for the blurring in an unfocused image, an important effect in all forms of imaging, from light microscopes to telescopes, but particularly in semiconductor lithography, where it can limit the size of transistors.

Fresnel was a highly religious civil engineer during the time of Napoleon. In 1817, Fresnel submitted his thesis to the Académie des Sciences for its Grand Prix on the topic of diffraction. Poisson, a committee member, pointed out that Fresnel's theory predicted a bright spot in the centre of the shadow beyond a coin, illuminated face-on by a small light source from the front, which was clearly absurd. When Arago, the chair of the committee, demonstrated exactly this spot experimentally using a 2-mm metal disk glued to a glass slide, Fresnel was awarded the prize. (A very small source of light must be used to observe this effect, in a very dark room, to provide spatial coherence.) This experiment, now demonstrated regularly using a laser light source in student laboratories, has become known as "Arago's bright spot," and provided decisive support for the wave theory of light. Fresnel also demonstrated that the undulations of light waves were transverse (like ocean waves), not longitudinal like sound. This created a serious problem for supporters of the Aether, since any elastic medium would support both longitudinal and transverse waves. But most significantly for our story this brilliant scientist produced a theory of Aether drag in 1818. Accepting that the refractive index was a ratio of light speeds, Fresnel postulated that the Aether wind becomes compressed when it passes through a medium such as glass or water, modifying the refractive index and changing the speed of light. His prediction agreed nicely with the measurements of Fizeau on the speed of light in moving water, which changed with the water speed. We now know that this was fortuitous, as Max von Laue showed in 1907. Einstein's theory predicts just this result without assuming the existence of any Aether, using his relativistic velocity addition formula. This fortuitous agreement was greatly to confuse scientists throughout the nineteenth century, during which experimental evidence in support of Fresnel's Aether drag theory accumulated. The acceptance of Fresnel's theory added to the shock when Michelson's work failed to find any evidence of an Aether wind in 1887. But the work Fresnel was most proud of (which he insisted be recognized on his tombstone) was his invention of the Fresnel lens used in lighthouses (Levitt 2013), which saved many lives at sea with its collimated search-light beam, rotated around the horizon.

Unlike Arago, Fresnel did not read or speak English. He was therefore unaware of the work of the great polymath, Thomas Young, his contemporary in London, who had already, in 1801, provided irrefutable evidence that light was a wave in one of the greatest experiments in the history of physics. Young's many achievements, including translation of the Rosetta stone, the definition of Young's Modulus and surface tension in materials science, the first correct definition of kinetic energy, and his explanation for the accommodation of the human eye, are well known (Robinson 2006). Inspired by the water waves seen in a shallow trough, he demonstrated controlled interference between light waves for the first time. Here is how he described his experiments in 1803 (Young 1845):

> I made a small hole in a window shutter, and covered it with a piece of thick paper, which I perforated with a fine needle. For greater convenience of observation, I placed a small looking glass without the window shutter in such a position as to reflect the sun's light in a direction nearly horizontal, upon the opposite wall, and to cause the cone of diverging light to pass over the table on which were several little screens of card paper. I brought into the sunbeam a slip of card about one thirtieth of an inch in breadth, and observed its shadow, either on the other wall or on cards held at different distances. Beside the fringes of color on each side of the shadow, the shadow itself was divided by similar parallel fringes, of smaller dimensions … Now these fringes were the joint effects of the portions of the light passing one each side of the slip of card, and inflected, or rather diffracted, into the shadow. For, a little screen being placed a few inches from the card, so as to receive either edge of the

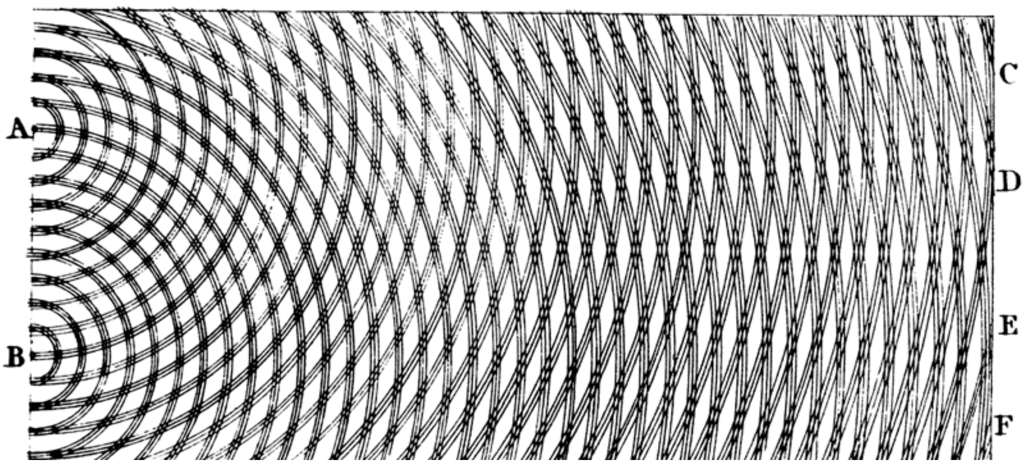

Figure 11. The drawing Young published to show interference between waves from two different small sources at A and B. The interference is constructive around D and E. (The sources A and B could alternatively be points where two small stones hit a still pond at the same time). (From Robinson 2006.)

> shadow on its margin, all the fringes which had before been observed in the shadow on the wall disappeared …

In other words, the interference fringes in the shadow region caused by light passing around either side of the card and overlapping at the viewing screen disappeared if he blocked the passage of light on one side of the card, demonstrating interference. But Young is much more famous for a second similar experiment around 1807 in which he used a needle to make two small holes in an illuminated card. On a distant screen he saw the interference fringes shown in **Figure 11**. It is not entirely clear that he actually did this experiment, unlike the first, but these "Young's fringes" are readily formed in this way using modern equipment, and have been described by Richard Feynman[14] as "containing all the mystery of quantum mechanics." This is because, using a light source so weak that only one photon at a time leaves the source (even an hour apart), it will be found that the dots at the detector screen indicating arrival of photons slowly build up, like a Pointillist painting, into the pattern of interference fringes seen by Young when using continuously flowing light. *How does each photon know where to arrive to build up this pattern?* Quantum mechanics predicts exactly this phenomenon, but the underlying reasons are not understood, and form the background for much of the debate about quantum weirdness (Gribbin 2014).

It is interesting that Newton had anticipated the discovery of interference, in which overlapping waves coming from different directions can build up wave height. Newton had used this idea to explain the tides at Batsha Bay in the Gulf of Tonkin in Vietnam, where travellers reported the strange phenomenon of a completely static water level for one entire day every fourteen days, between which there was only a single slow tide, increasing and falling.[15]

Fresnel, unaware of Young's work, had rediscovered interference effects in 1815, but acknowledged Young's priority in a letter to him in 1816. Following Fresnel's death, Arago in his memoir of him writes vividly of his encounter with Young and particularly his wife:

> In the year 1816, I passed over to England with my learned friend M. Gay-Lussac. Fresnel had then just entered in the most brilliant manner into the career of science by publishing his *Mémoire sur la Diffraction*. This work … became the first object of our communication with Dr. Young. We were astonished at the numerous restrictions he put upon our commendations, and in the end he told us that the experiment about which we made so much ado was published in his own work on *Natural Philosophy* as early as 1807. This assertion did not appear to us correct, and this rendered the discussion long and minute. Mrs Young was present, and did not appear to take any interest in the conversation, but, as we know, that fear, however puerile, of passing for learned ladies — of being designated blue-stockings — made the English ladies very reserved in the presence of strangers, our want of politeness did not strike us till the moment Mrs Young rose up suddenly and left the room. We immediately offered our most urgent apologies to her husband, when Mrs Young returned, with an enormous quarto under her arm. It was the

[14] Feynman (1992), p. 130.

[15] See Cartwright (2003).

first volume of the *Natural Philosophy*. She placed it on the table, opened it without saying a word, and pointed with her finger to a figure where the curved line of the diffracted bands, on which the discussion turned, appeared theoretically established.

Arago, writing here not long after the French Revolution (*Liberté! Égalité! Fraternité!*), and a liberal at heart, perhaps wants us to understand that the educated ("*blue-stocking*") ladies of France were more "liberated" than their English counterparts.

Electromagnetism in the 19th century

The understanding that light was an electromagnetic wave, related somehow to electrostatics (stationary charges) and magnetism (the magnetic fields which arise when charges are in motion), came slowly throughout the nineteenth century (Darrigol 2000, 2012). At the start of that century, these two topics were considered entirely unrelated, and the nature of electricity was not understood at all. The towering figure responsible for the synthesis and foundation of the entire subject of electrodynamics was James Clerk Maxwell (1831–1878). Maxwell's theory was largely based on the work of the great experimental genius Michael Faraday, about whom much has been written (Thompson 1901). For our purposes, two of Faraday's discoveries were critical: first, his invention of what is now called Field Theory. Here, on seeing metal filings line up in arcs on a card placed across the poles of a horseshoe magnet, Faraday imagined that they lay along lines of tension (field lines) in the Aether, like rubber bands (with sideways forces). Perhaps he bumped the magnet, causing the grains of metal to vibrate, since in a letter to Maxwell he also suggests that this might be the mechanism of electrical radiation. He wrote that he "*considered radiation as a high species of vibration in the lines of force which are known to connect particles and also masses of matter together*," a brilliant physical insight for the time. His second crucial discovery relevant to the speed of light was rotation of the direction of polarization of light passing through a medium subject to a magnetic field: the magneto-optical effect. This was the first experimental connection between electricity and light, apart from the electrical sparks studied by Benjamin Franklin in thunderstorms. William Thomson (later Lord Kelvin) formulated a mathematical theory of the effect, which provided the crucial displacement currents for Maxwell's theory. These arose from spinning magnetic vortices, or idler wheels, in his Aether medium, as shown in **Figure 12**. In his three great papers from 1861 (Simpson 2006)[16], Maxwell constructed a mechanical model of an elastic Aether which would support the propagation of electromagnetic waves. These were based in turn on ideas taken from Fourier's theory of heat, from existing work on fluid dynamics (electricity could be imagined as a flowing fluid), and on Newton's equations for elastic media describing the forces between electrical charges and currents established previously by Coulomb and Ampere. In his last paper of 1865, based on energy-conservation methods, he discards the Aether scaffold entirely. The paper ends with a simple prediction for the speed of light (independent of the speed of any light source) in terms of the two "elastic" constants of the Aether only, constants we now describe as the permittivity and permeability of a vacuum. Heaviside later described the Aether as "a dielectric." It was the symmetry

[16] Simpson (2006) contains Maxwell's three great papers on electrodynamics and detailed analysis.

in these equations created by the displacement current (a time-varying magnetic field produces an electric field, and vice-versa) which provided the important clue for Einstein in his 1905 relativity paper. Maxwell's great book of 1873 contained his twenty equations in an appendix, later reduced to the modern four equations by Heaviside in 1884.

By accurate measurement of the permeability and permittivity using a current balance of his own devising (described below as "measuring the quantity of electricity"), Maxwell was able to deduce the speed of light from his formula. In 1864, announcing one the greatest discoveries of 19th century science (that light was an electromagnetic wave), he wrote:

> The velocity of light in air, by M. Fizeau's experiments, is v = 314, 858, 000, according to the more accurate experiments of M. Foucault it is v = 298,000,000. The velocity of light in the space surrounding the Earth, deduced from the coefficient of aberration and the received value of the radius of the Earth's orbit, is v = 308,000,000. Hence the velocity of light deduced from experiments agrees sufficiently well with the value of v deduced from the only set of experiments we as yet possess. The value of v was determined by measuring the electromotive force with which a condenser of known capacity was charged, and then discharging the condenser through a galvanometer, so as to measure the quantity of electricity in it in electromagnetic measure. *The only use of light used in the experiment was to see the instrument.* The value of v found by M. Foucault was obtained by determining the angle through which a revolving mirror turned, while the light reflected from it went and returned along a measured course. *No use whatever was made of electricity or magnetism.*
>
> The agreement obtained seems to show that light and magnetism are affectations of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electrodynamic laws.

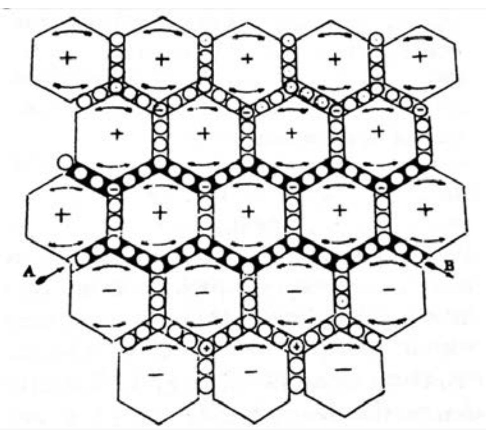

Figure 12. Maxwell's model of the elastic Aether with spinning vortices, used for his theory of light waves, from his 1862 paper. (From Simpson 2006.)

It seems almost miraculous that Maxwell could arrive at these Lorentz-invariant equations (meaning that the speed of light is constant as measured in different moving frames) by using Newtonian equations (known not to be Lorentz invariant). Maxwell's work is one of the greatest examples of the way in which physicists used an imaginary system, in this case the elastic Aether, as a metaphor on which to base a mathematical model. Einstein, who said that "imagination is more important than knowledge," was to show that the metaphor was superfluous. But, without it, we would not have Maxwell's equations, the basis of all modern electrical engineering and telecommunications.

Maxwell, whose wife Katherine was highly religious, could recite long passages from the scriptures. He was a skilled horse-rider, played the guitar and wrote much occasional verse. His biographers (Campbell & Garnett 1884) give a charming portrait of Maxwell at work in his laboratory, quoting from one of his letters in 1878 soon after the telephone was invented:

> We have all been conversing on the telephone. Garnett actually recognized the voice of a man who called by chance! But the phonograph will preserve for posterity the voices of our best singers and speakers. I have been making a clay model of Prof W. Gibbs's thermodynamic surface.

Campbell, who knew Maxwell well, writes of him:

> He had a strong sense of humour, and a keen relish for witty or jocose repartee … his mirth was never boisterous, the outward sign being a peculiar twinkle and brightness of the eyes. Of serenely placid temper, genial and temperate in his enjoyments, infinitely patient, he at all times opposed a solid calm of nature to the vicissitudes of life (such as his painfully protracted death of bowel cancer) … In experimental work he was very neat-handed. When working, he had a habit of whistling softly a sort of running accompaniment to his inward thoughts. He could pursue his studies under distractions such as loud conversations. Then he would take his dog into his confidence, and would say softly, at intervals "Tobi, Tobi … it must be so. Plato, thou reasonest well." He would then join in the conversation.

It was around this time that the Atlantic telegraph cable was laid, as shown in **Figure 13**. Engineers were baffled when the Morse code signals did not arrive at the speed of light. Kelvin explained that the capacitance of the wire spread out the pulses. The first message from Queen Victoria to President Buchanan took 16 hours for 99 words — at a rate of 0.2 bits per second! Maxwell died in 1879, eight years before Heinrich Hertz discovered radio waves.

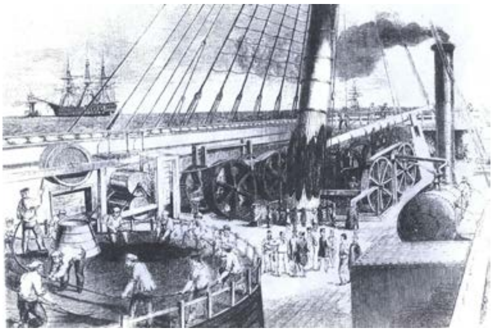

Figure 13. Lord Kelvin (on deck at center of group) on board the HMS Agamemnon (US Niagara in distance) during the laying of the first transatlantic telegraph cable in 1857. Morse code was expected to run under the Atlantic at the speed of light — it didn't! (Provided to the author from US Navy archives.)

Albert Michelson and the Aether wind

Albert Michelson, the first American to win the Nobel prize, was born in Poland, to a family who soon moved to San Francisco. President Grant supported him at the Annapolis Naval Academy, where he graduated in 1872. Soon after he dedicated his life to experimental science aimed at locating that absolute frame of reference in the Universe, the Aether (Michelson 1903). In Helmholtz's laboratory in Berlin he invented his famous interferometer (perhaps derived from the Jamin interferometer[17]) and published first results from it in 1881. Here he sought to measure a difference in the speed of light running across, and along the Aether wind, but

[17] https://en.wikipedia.org/wiki/Jamin_interferometer

found none. Like the Jamin, his interferometer benefits greatly by division of the amplitude of the wavefield across the entire area of the wavefield, rather than Thomas Young's weaker division of wavefield at two points. It is likely that Michelson got the idea for his great experiment from the article Maxwell wrote for the 9th edition of the *Encyclopædia Britannica* in 1878, the year before he died, in which he assumed that the Aether was fixed to the centre of our Milky Way galaxy, around which the Sun orbits. Maxwell proposed using Rømer's method first to measure the speed of light traversing the Earth's orbit around the Sun in one direction, and then to repeat this when the light coming from Jupiter to Earth was travelling in the opposite direction, after Jupiter had gone half way around its orbit around the Sun. Maxwell had written to a colleague of Michelson's, David Todd, asking for the required astronomical data on Io's orbits, in a letter which Michelson read in 1879. (Einstein was five days old). Maxwell pointed out that his proposal was a stronger one-way "first-order" effect than the round-trip "second-order" measurements of Fizeau and others.

Discouraged by the negative result and lack of response to his 1881 Berlin paper, Michelson despaired of a further career in physics. But he found himself at dinner in Baltimore with the Lords Kelvin and Rayleigh in 1884, who had read his paper and strongly encouraged him to try again in his new position at Case Western University. An extended correspondence thus began between Michelson and Rayleigh. The famous interferometer which Michelson and his colleague Morley built at Case is shown in **Figure 14**, which Michelson spent two years perfecting. Briefly, coherent light from a sodium lamp is divided into

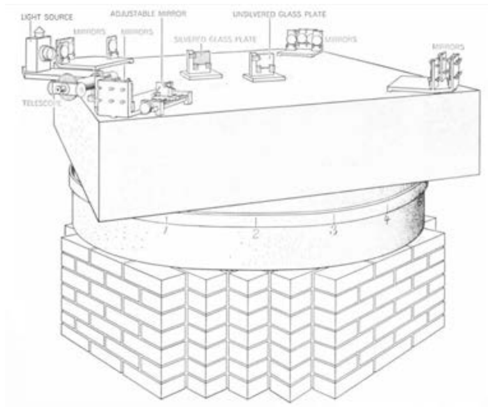

Figure 14. Michelson's interferometer, used to detect any motion of the earth through the Aether. To reduce vibration the optics were mounted on a five-foot square sandstone slab a foot thick, and the supporting brick pier reached down to bedrock. To allow it to be rotated smoothly, the interferometer floats on a trough of liquid mercury, which also relieved any stresses in the materials. (From Shankland 1964b.)

two paths, running, say, across and along the direction of the Aether wind, and then recombined, to interfere. These interference fringes are extremely sensitive to the smallest differences in the speed of light along the two paths. Like water waves on a flowing river, they expected the light waves to pick up, as a tailwind, the speed of the Aether wind, thus moving the interference fringes. Repeating observations six months later, when the Earth had reversed its velocity through the Aether, they expected to see changes in the positions of the fringes, but did not. They could also rotate the entire interferometer, which floated on mercury (Morley's idea) to look for fringe movement, but any movements were negligible. They could detect an Aether wind velocity as small as 5 km/s, compared to the Earth's speed of about 30 km/s.

Thus was published in 1887 what some have described as "the greatest null result in the history of science," that the speed of light is to be the same in any direction (Shankland 1964a). Not often mentioned in textbooks is their conclusion that the hypothesis of a stationary Aether (an absolute frame of reference in the Universe) was untenable. Most scientists were extremely reluctant to accept this idea, since it suggested the alternative and highly implausible idea of "complete drag," that the Aether was fixed to the Earth and rotated with it, or, as Michelson suggested in his paper, his work supports the "partial drag" theories, in which a layer of Aether near the surface of the Earth was dragged around with it. An important technical discussion followed in the literature as to what exactly was being measured — the phase (wavefront) or the group (pulse) velocity, led by Rayleigh. It was concluded that all experiments measured group velocity except Bradley's, which measured phase velocity.

Einstein: the great clarification

The last years of the nineteenth century produced a frenzy of intellectual activity in the effort to make sense of all this, with the most important contributions coming from Hendrick Lorentz (the physicist Einstein admired the most), George FitzGerald, and later Henri Poincaré. FitzGerald was the first to suggest, in a completely overlooked paper in 1889 (in the obscure new American journal *Science*), the apparently crazy idea that objects (such as Michelson's interferometer) would contract in the direction of their motion at high speed, accounting for Michelson's null result. This was consistent with Heaviside's earlier publication showing that the field lines and potential surface around a moving charge do contract in the direction of motion, so that if matter consisted of charged particles, it should shrink. FitzGerald, a scientist generous with his highly creative ideas and supportive of others, also pre-empted the discovery of radio (FitzGerald 1883). Lorentz had suggested, before Einstein's 1905 paper, the even more astonishing idea that time itself slows down if you go fast enough, relative to someone at home, as had Larmor (1900).

In summary, around 1900, when Lord Kelvin spoke at the Royal Institution, the situation was as follows:

1. Maxwell's equations, which provided a constant velocity of light, suggested an absolute reference frame, supporting a stationary Aether through which the Earth moved.
2. Michelson's experiment: no stationary Aether, possibly George Stokes' improbable "complete drag" theory, where the Aether is attached to the Earth and rotates with it.
3. The violation of the Galilean transformation for light. Unlike waves on a river, the speed of light waves did not seem to add to the speed of the Aether "current."
4. The aberration of starlight — no "complete drag." No tilt of a telescope is needed if the Aether is fixed to planet Earth.
5. Excellent agreement of several measurements of Aether drag with Fresnel's theory, such as Fizeau's demonstration that the speed of light in flowing water was proportional to the water speed.
6. Newton's laws were independent of inertial frame under Galilean transformation, but Maxwell's were not — the speed of light was the same in every frame. Inertial frames are those moving with constant speed with respect to each other.

There were three ways to reconcile these results: First, find the Aether, an absolute frame of reference. Second, repair Maxwell's equations, so that they obeyed a Galilean transformation. Third, fix Newton's equations, so that they obeyed the new Lorentz transformation, which kept the speed of light constant in all inertial frames.

Einstein's 1905 paper on "The electrodynamics of moving bodies," in which he introduced relativity, clarified and reconciled all these issues at a stroke, by incorporating both seemingly crazy ideas (time dilation and length contraction), abolishing the Aether entirely, and claiming that the speed of light was a constant (given by Maxwell's value), independent of the speed of its source. This means that the speed of light coming toward you from car headlights at night does not depend on the speed of the car. With no Aether, and a constant speed of light, the result of Michelson's experiment was immediately explained. With extraordinary confidence for a twenty-six year old patent attorney in Bern, Einstein (who had portraits of Faraday, Newton and Maxwell in his office) chose the third option, modifying Newton's equations to make them Lorentz invariant, the change that produced $E = mc^2$ in another paper published later in 1905. This means that mass m is a form of stored energy E, as released in the nuclear reactions in our sun and the stars (Rhodes 1986). But sorting out this mess was an achievement of genius — whereas the symmetries in Maxwell's equations and the results of the Michelson-Morley experiment supported his notion that all motion was relative, the results from the aberration of starlight and Fizeau's finding that the speed of light depended on the speed of a moving water medium, were at first harder to understand (Pais 1982)[18]. The agreement with Fresnel's theory turned out to be fortuitous, as we have mentioned. Einstein's paper contained other new results: a derivation of a new relativistic transverse Doppler effect, and a relativistic treatment of the aberration of starlight using the correct velocity addition law. The breakthrough came with his new understanding of the relativity of simultaneity and time dilation, which reconciled all these results, and led to a completely new understanding of the nature of time itself.

Einstein realized that time intervals are measured by the coincidence of events, but these depend on the relative velocity of observers, as we explain below.

Einstein's paper made two assumptions, that the speed of light was the same in all inertial frames, and that all physics experiments (such as games of snooker played on smoothly running trains going at different speeds in different directions) should give the same results in all inertial frames. These frames were co-ordinate systems moving with constant velocity with respect to each other, one of which could be "stationary." He provided the correct transformation rule to allow the stationary observer to predict what an observer in a second moving frame (such as a car moving at constant speed) would measure, regarding events seen from both frames. This "Lorentz transformation" had been published the previous year (1904) by Lorentz, derived in electrodynamics from the requirement that light have Maxwell's velocity in all inertial frames. Einstein does not reference this paper, although he was well aware of the work of Lorentz and

[18] Pais (1982) is the best biography of Einstein, containing much historical and technical information from someone who worked with him.

Michelson. His derivation of the Lorentz transformation is based on entirely different physical arguments. He then applied this transformation to the measurement of time and length intervals and so predicted time dilation and length contraction. The essence of one of these physical arguments (and of special relativity) can be described as follows.

Imagine flying from Sydney to Canberra at night. Assume that the lights of both cities are turned on at the same instant. A person on a high mountain exactly midway between the cities would see both city lights come on at once. But for an observer in a fast aircraft, since light has finite speed, during the time the light was travelling from Canberra to the aircraft, the aircraft would have moved forward a little. For that observer the Canberra lights were indubitably turned on first. This is the relativity of simultaneity, and the important point is that both observers are correct, and every observer in a different frame would judge the sequence of events differently. Because Einstein's theory does not allow causal influences to travel faster than light, it is not possible to violate causality in this way: events cannot precede their cause. The relative simultaneity paradox arises from the nature of space–time itself. Extending this type of argument led Einstein to the idea that moving sticks get shorter (as measured in a stationary frame) and moving clocks run slow (compared to a stationary clock). This has been demonstrated many times, for example by sending one of two synchronized clocks on the space shuttle and comparing them on return.[19]

It was said that it was easier to understand the mathematics of special relativity than the physics of it, and very difficult to accept replacements for Newton's laws, due to his immense authority. As one professor in physics has commented "in physics, mathematics can easily be a substitute for thought," a view which Thomas Young wrote strongly in support of. (Young wrote his equations in words.) A recent delightful and amusing book discusses the exaggerated importance given to the "beauty" criterion for new equations in the sub-atomic high-energy particle physics community (Hossenfeld 2018). This was never the case for Einstein, especially as a young man, for whom physical intuition always came first. In his later years he did turn increasingly toward more formal mathematical manipulations in his unsuccessful pursuit of his unified field theory.

Conclusion

This remarkable intellectual history of ideas started with Newton's action-at-a-distance principle, the idea that gravity and light act instantaneously across the Universe. This held sway until the time of Rømer and Bradley, who provided the first strong experimental evidence for a finite speed for light. These measurements were vital in helping to provide a time and distance scale for the Universe, solar system and Earth (important for Darwin's theory). Competing explanations for refraction brought disagreement between those who thought light was a wave and those favouring a particle model in an elastic, invisible Aether which somehow could not support longitudinal waves.

Thomas Young next showed that light, split into two beams, can be recombined to produce interference fringes, in exact accordance with a wave theory of light. Faraday, the great experimentalist, was the catalyst for many major theoretical insights. He saw in his iron filings tensioned lines of force, along which waves might travel, giving birth to

[19] Ed.: sat-nav systems successfully adjust for these effects.

field theory and a finite velocity for light. His discovery of the rotation of the polarization of light led Maxwell to the concept of his displacement field. Later, this helped to explain how radio waves propagate, as FitzGerald was the first to understand. Magnetism, electrostatics, and optics were unified by Maxwell, with his mechanical model of the Aether, later discarded, and his demonstration that light was an electromagnetic wave, for which he provided a constant speed (in terms of electrical constants) which did not depend on the speed of the source of the light. This added support for the existence of a frame of absolute rest in the Universe, the Aether, which supported the propagation of light waves.

Fresnel's Aether drag theory supported experiment for a century, while the brilliant terrestrial measurements of Fizeau, Foucault and Michelson both improved on the accuracy of lightspeed measurements and addressed the problem of light propagation in a moving medium. This culminated in Michelson's null result, which gave the same speed for light in all directions on a moving Earth.

Poincaré and Lorentz anticipated many of Einstein's 1905 results but retained the idea of an Aether. Einstein finally wrapped it all up and clarified everything in 1905 in a theory which also, as a result, could extend Newton's laws to the very high energies and speeds of nuclear physics and so predict the energy release from atom bombs. His theory connects space and time through the speed of light.

This brief history of measurements of the speed of light and of the concept of the Aether has overlooked many fascinating associated discoveries, such as the discovery of radio (anticipated by the remarkable David Hughes) by one of the greatest experimentalists and theoreticians, Heinrich Hertz in 1887 (Hertz 1893, Fahie 1899). Hertz applied Maxwell's equations to his discovery (at first called "invisible light") and promoted the adoption of Maxwell's work in Europe, despite the alternative formulation of his supervisor, Professor Helmholz. Nor have we discussed "superluminal" schemes for communicating at speeds faster than light (Herbet 1988), closely related to Bell's theorem (Mermin 1990), today's quantum encoding methods using entangled states, and quantum computers (Gribbin 2014, Gerry & Bruno 2013). Sufficient to say that no superluminal schemes have succeeded. Greek astronomy, radio, Hughes, entangled states and Bell's theorem are discussed in more detail in Spence (2019).

The speed of light is one of a very small number of fundamental constants in physics which truly determine the nature of our Universe and the form of matter within it. It is the constant c in Einstein's most famous equation $E = mc^2$ linking mass and energy, and its measurement has driven advances in technology, notably in interferometry, GPS navigation and astronomy, by some of the greatest builders of scientific instruments. The speed of light has been described by S. R. Filonovich (1986) as the constant which provides "a clear manifestation of the unity of our physical world." And the discovery that light does not travel instantaneously tells us, as we look up into the night sky at distant stars, that we indeed are looking back in time. The history of the measurement of the speed of light follows one of the greatest intellectual adventures in human history, at the heart of progress in science over the last four hundred years, and central to the wave–particle duality, the idea that light can be thought of as either a wave, or a particle.

We must end this odyssey by pointing out that the speed of light is no longer measured: it was given a defined value in terms of other standards (of length and time) in 1983 (Barrow 2002). In May 2019 the last international standard based on an artifact (the kilogram of mass) was also eliminated and re-defined in terms of other standards.[20]

In trying to understand the nature of the medium which conveys light in vacuum, we might end by observing that the modern quantum field theory of the vacuum state (supporting, for example, the zero-point energy and the Higgs boson) perhaps just replaces one kind of Aether with another.

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[20] See Hibbert (2017) on its demise. [Ed.]

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Polymers: a historical perspective

Robert Burford FRSN

Emeritus Professor, School of Chemical Engineering, UNSW Sydney

Email: r.burford@unsw.edu.au

Abstract

This commissioned paper outlines the emergence of new forms of synthetics and plastics as our understanding of polymer chemistry has advanced.

Synopsis

Polymers have been ubiquitous since simple gaseous molecules began to form life-giving organic structures many millions of years ago. Today, we rely upon proteins comprising twenty amino acids, as well as DNA and RNA with many fewer nucleic acids. Similarly, many fibres and plants comprise carbohydrate polymers: we and other animals use these and protein-based polymers for our diet. Hence, organic earth's surface has an enormous diversity of naturally occurring polymers, sometimes called macromolecules.

Today, these continue to feed and clothe us, and much more, but the beginning of man-made materials might be considered to be the transition from entirely natural materials to either substitutes or modified macromolecules. This period might be classified as the "precursor age" of synthetic polymers. It originates from the early 19th century and is an exciting period of amateur science, entrepreneurship and considerable skulduggery. A theme that continues today is the replacement of conventional materials with improved or cheaper substitutes.

The second period relates to entirely synthetic polymers which have as raw materials small molecules that arise from processing of coal or oil. Aromatic compounds such as phenols and styrene are "polymerised" to form thermosets,[1] including phenol formaldehyde "Bakelite" thermosets, but are also present in thermoplastics[2] including polystyrene and related materials such as styrene acrylonitrile (SAN) and ABS.[3] The manufacture of Bakelite is often viewed as the birth of the synthetic polymer industry. The enormous growth both in diversity and volume of thermoplastics is a feature of the 20th century, dismissively called the "plastics age." Again, important but sometimes serendipitous discoveries are a feature of this period, but the associated large-scale production introduced multinational corporations originating mainly in Europe, the US and Japan.

From the late 1930s, polymers based on ethylene and propylene, gases formed from "cracking"[4] of naphtha or ethane/propane, have become commonplace. Their versatility and low cost have led to packaging and other single-use modes, which, in the absence of careful social behaviour, contribute markedly to unacceptable waste. This period of commoditisation is characterised by a transition from gleeful acceptance from the 1940s to the '60s to misgivings and apprehension in the 21st century.

[3] Acrylonitrile butadiene styrene

The First Age of Polymers

The beginnings of human exploitation of natural polymers might date from the use of timber, including fire, many millennia ago. The use of natural fibres including various wools is another prehistoric example.

More recently, the creative application of an isolated polymer might start from the recreational use of coagulated rubber from *Hevea braziliensis* by the Aztecs and others in Mesoamerica, as observed by Europeans in the 15th and 16th centuries.

The history of rubber is fascinating, as it combines great wealth with slavery, not just in South America, but in South East Asia and in Africa. This was convincingly broadcast by the late Professor Peter Mason (1979).

It is also documented extensively, for example in Stahl (1984) and Fenichell (1996). This latter text provides excellent case studies that are drawn upon elsewhere in this paper.

Here the emphasis is placed upon the deliberate manufacture of either new but modified materials that can be processed to take on desired forms, or, later, entirely new synthetic polymers (predominating in the Second Age). In many ways, however, synthetic polymers cannot match natural materials and this remains an aspiration.

The industrial age can be characterised not only by the harnessing of energy via the steam engine, but also the mass conversion of raw materials into refined or intricately produced products such as woven cotton and woollen garments. An examination of any technology museum will reveal a multiplicity of complex machines designed to value-add starting materials into consumer articles.

In this environment the opportunity for entrepreneurial inventors to make and sell new and desirable articles was compelling, and examples described below either replace scarce natural substances, or introduce new materials with novel properties. In this age, much work was conducted by energetic and creative, but somewhat uneducated, amateurs.

Although the primary focus in this paper is on plastics and to a lesser extent thermosetting materials, the exploitation of natural rubber illustrates several common themes.

Natural rubber was available from South America in the 18th century, and those controlling the plantations and essentially slave labour were becoming enviably wealthy. Opera houses, trams, electricity and much else was built in the Amazon beside a decimated native population. Saplings of these "rubber trees" were smuggled from South America and the survivors propagated in Kew Gardens. These in turn became the forebears of the globally distributed rubber plantations: pest species replacing native trees.

The next chapter was the need to make synthetic rubber to overcome the difficulties in sea transport of natural rubber to the UK and the US. The project was one of the underappreciated technical achievements of WW2. When I worked at the Australian Synthetic Rubber Company in the 1970s, secret codes both for raw materials and products, a legacy of the war, were still being used!

The transformation from a soft flowing and impure material to one that might be more valuable and useful was beset with technical challenges. Such challenges had to be overcome with a combination of mechanical changes as well as chemical modifications.

Natural rubber comprises *cis* poly isoprene, with (as we now know) a molecular weight of about 10^6 atomic mass units. Such a high molecular weight makes the material hard to process ("tough as boots") and with poor adhesion qualities, which limits its further deployment. This was addressed using a crude masticator known as the Hancock "pickle," akin to a torture instrument with multiple arrays of intermeshing teeth. The modified rubber was a marked improvement on the naphtha-dissolved rubber used by Charles Macintosh in the 1820s to waterproof garments.

Soon after, Charles Goodyear sought to improve the properties of "India Rubber" (named from the Caribbean Indies and from the ability of the polymer to erase pencil markings) with essentially no knowledge of chemistry at all. He tried numerous experiments with little success over more than a decade, with Goodyear in and out of debtor's courts and prisons. It was however the entirely accidental exposure of rubber latex to spilt sulphur on a stove that led to crosslinking, or vulcanisation, a technology still conducted today. Despite his 1844 patent, Goodyear died impoverished. This is a representative example of an important and enduring but accidental discovery.

A second important discovery was the modification of cellulose ester to render the material both transparent and malleable. The origins are fascinating and relevant. The Victorian era was largely decorated with ivory: piano keys, hairbrushes, knife handles and much else. Particularly challenging items were billiard balls, those having the best "click" made from the middle, clear grained section of Ceylonese elephants' tusks. Such was the supply and demand problem that a reward of $10,000 in gold was offered for invention of a credible substitute. Gun cotton (cellulose nitrate) was already known. Admixtures in solvent (collodion) were developed by John Hyatt in the 1860s to encase wood pulp and bone mixtures. Ultimately a suitable substitute was realised and the prototype remains (although the prize was not awarded), but Hyatt's main discovery was to follow.

This was the addition of camphor to nitrocellulose to make the material malleable, and millable into a thin coherent mass. This product — celluloid — patented in 1869, became the key product of the American Celanese Corporation, and celluloid formed the basis of photographic film technology and greatly affected both the photographic and movie industries. Hyatt himself left to begin the hotel company that bears his name to the present time.

In assisting the Powerhouse Museum conservation team in Sydney, I've had the opportunity to learn of the polymers available from about 1880 to the 1940s (from the Penfold collection,[5] amassed on a global tour) and to the present time. A surprisingly small number of polymer families existed, but in a diversity of manifestations. Many forms of ivory substitutes were available, sometimes with casein (milk protein) derived polymers. Celluloid materials, either cellulose nitrate or acetate, were also well represented. The former are dangerously unstable, whilst the acetate also loses acetic acid to leave brittle cellulosic residues. This is a major concern

[5] During the period 1929–55, the Powerhouse Museum director Arthur de Raymond Penfold became fascinated by plastics, the new material, and stated: "The way they stirred the imagination of the public is as much a marvel as the wizardry of the modern organic chemist who gave us the great invention." (Taylor 2010)

for the movie industry, with many endangered cellulose acetate films still at risk.

Another extensively represented polymer is Bakelite, phenol formaldehyde often filled with wood flour or fibres: the default material for telephones, piano rolls and much else. The Powerhouse Museum and similar institutions have vast collections of items made from Bakelite and similar thermosets. This historic material is notably still used for saucepan lids and handles, and allied thermosets are used in modern electronics including mobile phones. Hence even ancient polymers can be enduring.

Whilst celluloid became enormously successful through Eastman's Kodak business, a truly synthetic material was soon to emerge. Leo Baekeland[6] had initially developed a superior film[7] for Eastman for which he was extravagantly rewarded. Although the reaction between phenol and formaldehyde was known by Adolf Bayer in 1872, and casein, made from milk protein and formaldehyde, had also been invented in 1899 and is still used for buttons, the production of a valuable insulating material made using phenol and formaldehyde (Bakelite) was delayed until 1907.

Baekeland used high temperatures and pressure to overcome volatile gas formation that had rendered prior materials unsuitable. This is another example of persistence and sometimes counter-intuitive ideas that extend beyond the basic chemistry leading to successful invention. Similar reactors for these and Novolac[8] resins are still provided in quite recent textbooks, and kettles were employed in Australia until the 1970s.

Although liquid precursor mixtures were also made that could fill moulds, once heat and pressure were applied the solid made was permanent. Such a "thermoset" remains resistant to heat and stress, and Bakelite represents the first entirely synthetic polymer with no naturally occurring precursor. The synthetic plastic age had begun.

Early applications included electrical insulators (which continued being made after WW2), billiard balls (replacing celluloid) and lawn/carpet bowls (familiar to older readers!). In contrast to many earlier inventors, Baekeland was well educated and positioned to exploit and improve upon many other discoveries. Although not impoverished, he appears to have died lonely and eccentric.

The period from 1910 to the 1930s was an exciting time for the industrial discovery and manufacture of new polymers, including linear polymers such as polyvinyl chloride (PVC) or "vinyl" in 1926 and polystyrene in 1931 that could be truly plastic, that is, made into a fluid and be re-mouldable. Both these polymer types had antecedents, with for example polystyrene being known as the non-pungent solid form of styrene and called "metastyrene."

Nicholson's 1997 text explains that the term "polymerisation" was coined in 1870 to address the transformation of a molecule with one physical form to another quite different one but with the same empirical formula (polystyrene from styrene in 1866). This was done in the absence of polymerisation theory as known today.

It was also a fascinating time from an academic and theoretical perspective as the concept of what the molecular structure

[6] The Belgian-American chemist Leo Baekeland developed Bakelite in Yonkers, New York, in 1907. The first issue of *Plastics* magazine, October 1925, featured Bakelite on its cover.

[7] Velox photographic paper, in 1893.

[8] Synthetic shellac.

of a polymer entailed was fiercely debated. Whilst Emil Fischer had carefully synthesised proteins with molecular weights up to 4200, according to Stahl's paper he did not formulate a detailed structure. There were other opinions supporting high molecular weight molecules, particularly with synthetic polyisoprene, but the conventional wisdom, which linked synthetic polymers with many naturally occurring systems, was of colloidal aggregates.

It was Hermann Staudinger who convincingly invented the term and concept of "macromolecules" in 1922, for which he was awarded the Nobel Prize in 1953, rather than the established associative model. He published papers starting from 1920 which remain rigorous today, relating initially to polystyrene and polyoxymethylene and then to many others.[9] Again according to Stahl's record, Herman Mark, then an X-ray crystallographer and subsequently a pioneer in the forefront of polymer chemistry, mediated between the protagonists.

Such intense debate is not unusual. The availability of new information by neutron scattering added fire to the debate about chain alignment in crystallisable polymers, for which some supporters came to blows at a conference in the early 1980s! A key factor in science and medical Nobel Prize success is the unexpected nature of the research.

The increasing awareness and adoption of the macromolecular concept aligns well with the amazing research by Wallace Carothers at DuPont. Many polymer discoveries are accidental, not only by amateur chemists but also by "the prepared minds" who see the value of the unexpected, including quite recent findings. Hence, the discoveries of PVC in 1926, polyethylene in 1933, Teflon in 1938, metallocene catalysts and conducting polymers (including polyaniline) all entail lucky breakthroughs. The inspiring aspect of the polycondensation activities of Carothers was the intentional and systemic nature of that creative chemistry.

Carothers was associated with the development of polychloroprene in 1932 (DuPont trade name Neoprene) which has many properties superior to natural rubber, but Carothers is best known for polycondensation polymers, including polyesters and polyamides and nylon. Many of the fascinating commercial aspects of the latter are given in Chapter 6, "Nylon" in Fenichell (1996, pp. 19–22).

A concise (8-page) and authoritative online document from the American Chemical Society (2000)[10] is also recommended. The ACS stated in 2000 that about half the industrial chemists in the US were working in polymer chemistry.

With hindsight it seems simple to take well-known reactions between dibasic[11] and diacid small molecules to make amides and esters. Indeed I used this to illustrate to undergraduate students, (with mixed success), the systematic nature of chemistry. A simple monoester reaction (ethyl acetate), followed by more complex reactions and then a di-ester reaction to form the polyethylene terephthate (PET, 1941) used in soft drink bottles followed. The di-amide reaction to give the DuPont nylon followed by 1935.

[9] See "The Foundation of Polymer Science by Hermann Staudinger (1881-1965)"

[10] Commemorative Booklet—The Establishment of Modern Polymer Science By Wallace H. Carothers (PDF)

[11] *Dibasic*: containing two carboxylic acid –COOH groups.

A key challenge was to increase molecular weight so that chains can entangle and not only offer adequate mechanical properties, but also to form fibres, and this requires extremely high conversion. According to the ACS article:

> By the time DuPont started building its first plant in Seaford, Delaware, in 1938, more than 230 chemists and engineers had worked on the project at one time or another at a cost of $27 million.

Both polyesters and polyamides remain successful moulded plastics and fibres, with PET in particular now a large volume, cheap commodity polymer.

Whilst nylon was indeed an amazing polymer, with 800,000 pairs of stockings sold on 15 May 1940 alone, and many parachutes saving lives when the US entered WW2 in 1941, there are other more sobering aspects. Carothers himself committed suicide in 1937, a year after his marriage. And to some extent the stockings were promoted on a lie, that they, unlike silk, were claimed not to run.

The Second Age of Polymers

If the Penfold collection of polymers is analysed, it becomes clear that only a small fraction in volume of those we are familiar with now are represented. During the 1940s, perusal of the newly published *Australian Plastics Journal* reveals from both papers and advertisements that available plastics were confined to cellulosics, Perspex (poly methyl methacrylate, 1934), polystyrene, polyvinyl chloride and newly available polythene in 1933. The latter was by today's measure extremely expensive, a plastic bag costing about a day's salary. Synthetic rubbers and many thermosetting resins including urea and melamine formaldehyde compounds were used in large volumes, and were also employed as laminates and coatings.

From the 1940s to the 1970s a very substantial expansion in industrial polymer manufacture occurred globally, including in Australia. PVC, polystyrene, synthetic rubber, polyethylene (PE) and polypropylene (PP, 1954) were all made, with several Australian plants being in the vanguard. The slurry process used by Shell for PP in Rosehill, NSW, and the Ziegler process for polybutadiene (invented in 1928) by the Australian Synthetic Rubber Co. were some of the first globally.

Today PE and PP are ubiquitous and represent well over half the volume of polymers made globally. This reflects the enormous growth in polymers based on ethylene and propylene, both gaseous intermediates, either from cracking of naphtha (a kerosene-like fraction from oil refining) or dehydrogenation cracking of saturated natural hydrocarbon gases.

Their manufacture, however, has been challenging and adventurous. Low-density (LDPE) or branched polyethylene was and remains the result of extremely high pressure equipment that only became possible in the 1930s. When ICI scientists somewhat randomly explored how a mixture of benzaldehyde and ethylene would behave, they carefully noted that the ethylene hadn't magically disappeared but had formed a thin coating: polyethylene (or polythene); the beginnings in 1933 of a strategically important and subsequently lucrative industry.

Accounts by those involved vary somewhat, reducing the chance element, but remain vital historical records; for example, Raff & Allison (1956, Chapter 1) and McMillan (1979, pp. 10–14). Replicate experiments failed until the trace of an oxidant in the benzaldehyde was realised to be the key to success in making LDPE. Again multiple fortuitous accidental incidents came into play.

This material was a valuable for it represented the first flexible insulator and was initially employed for submarine cables, but more crucially for radar.[12]

LDPE remains a significant global material today, despite its low modulus and melting point. It has a "softness" and transparency that makes it "user friendly," and it continues to have an important place in packaging, where toughness can be equally important. LDPE, along with other polyolefins, is used extensively for single-use applications and is heavily represented in plastics waste streams.

A second and dramatic development was the discovery and use of catalysts to make both a new family of polythenes (Karl Ziegler in 1953) with linear chains (high-density polyethylene HDPE) and polypropylenes (Giulio Natta) where the stereoregularity about each second backbone carbon is controlled.[13] The history of this is detailed in McMillan's book and much has been recorded in standard polymer science textbooks, in the Nobel Prize of 1963 Records, and in technical papers and magazines. HDPE and isotactic polypropylene comprise about half the volume of all polymers, reflecting their excellent mechanical and thermal properties and low cost. Their uses extend beyond single-use packaging to strong containers, hot water jugs, casings for irons, and, now, banknotes in many countries.

[12] During WW2 it was a state secret.

[13] In 1963 Ziegler and Natta were awarded the Nobel Prize in Chemistry for their discoveries in the science and technology of polymers.

Their low density (less than water, even in bulk form) and high durability, especially when stabilised, contributes to their being a commonly found part of the waste stream both on land and in water.

It is perhaps difficult to believe the excitement and easy adoption of plastics in the 1950s and 1960s. However, conventional precursors made from ceramics and glass, as well as metals, were often heavy, brittle or liable to rust. There was also a fascination with the new and synthetic, and plastics did not have the connotations that they have today. Although the scene where Dustin Hoffman is advised, "I have only one word, Plastics" in the 1967 movie *The Graduate* might be viewed as somewhat cynical or ironic, it possibly just reflects a small turning point from popular consumer embrace.

Although research in biological macromolecules was being undertaken in Australian universities in the 1950s, synthetic polymers became a focus from the 1960s, with the establishment for example of the Polymer Division of the Royal Australian Chemical Institute and their annual Australian Polymer Symposia. These have not only attracted many famous international authorities, but also showcased top Australian academics, several becoming leading figures in subjects from emulsion polymerisation to newer types of synthesis (for example, RAFT, reversible addition-fragmentation chain transfer polymerisation) and much else.

CSIRO has had a very strong impact, examples being the shrink-proofing of wool using nanothickness coatings of polyurethane (invented in the 1930s), and the introduction of polymer banknotes in 1988.

Incidentally, Fenichell's text (1996, p. 28) mentions that the Swiss editor of *Annalen* *der Physik und Chemie*, J.C. Poggendorf, stated in 1846 in relation to nitrocellulose:

> Your glass-like paper is splendid. I hope you can make it thick enough to use for window panes … Might it not also make a good replacement for ordinary paper for bank notes?

The Hawke Government brought into being Cooperative Research Centres in 1991 to encourage a combination of research providers to assist Australian industry. The CRC for Polymers undertook many demanding challenges, ranging from agrifilms that degraded in a controlled way, to cables that endure fires.[14]

The Third Age: Is The Honeymoon Over?

The low-cost and continuingly improving properties of polymers, combined with growing affluence and increasing population, have all contributed to seeing an enormous volume of discarded polymer waste. Such outcomes should come as no surprise. As early as 1944, Fleck wrote:

> Plastics have a very definite and very useful future ahead of them, but undesirable publicity and wrong design can blast that career.

More recently, in a prophetic 1989 address, Dr A. MacLachlan, then Senior V-P, Technology at Du Pont, stated:

> One of the most important challenges for the future of the polymer industry is refining the processes used to make and form polymers and the methods used to dispose of them. Whilst it has been estimated that only 8% of the waste generated in the United States is synthetic polymers, their durability and visibility magnify the problem in the eyes of the public. Attitudes towards plastic products are becoming more negative. This problem must be addressed. New technologies to minimize and recycle waste must be developed … .
>
> If we do not have this mindset, we may find more and more environmental roadblocks appearing. In other words, we have to move from being problem creators to problem solvers. To the scientific community these are intriguing challenges. [MacLachlan, 1990].

The annual volume of plastics produced overtook all metals and glass several decades ago and continues to increase globally (although manufacturing has declined in Australia). High-volume, low-cost polymers continue to provide many solutions to societal challenges, from cataract lenses to lighter-weight motor vehicles and aircraft. Perhaps the affordability of many polymers has made them the subject of individual and industrial carelessness. A concise and thoughtful commentary was given by Paul Moritz in 2019.

Such waste issues have come to the forefront of politicians, media and the public, and already some remedies are emerging. Fully recyclable PET bottles are now available for beverages, and trends to thinner packaging are evident. However, much needs to be done, as identified by the Australian Packaging Covenant, including changes in public and corporate values. Clever technical solutions are inevitable, and in Australia this is already being encouraged by a Cooperative Research Centre for Plastics Recycling. Changes in social behaviour and a changing economic agenda both need consideration, and will take time.

[14] Andrady & Neal (2009) paint a similar picture [Ed.]

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Figure-ground and occlusion depiction in early Australian Aboriginal bark paintings

Barbara J. Gillam FRSN

Psychology, University of New South Wales, Sydney, Australia

Email: b.gillam@unsw.edu.au

Abstract

Aboriginal painting has been largely treated as conceptual rather than perceptual and its visual impact little examined. In this article, the author shows the perceptual skill and innovation demonstrated by Aboriginal bark painters in depicting figure-ground and occlusion. This has heuristic value for studying occlusion perception and adds visual meaning to the conceptual meaning of the paintings.

Introduction[1]

Aboriginal people lived in Australia for over 40,000 years before European settlement in 1788. They had a rich ceremonial culture with beliefs and stories about creation, ancestral beings and the land. These stories had longstanding visual expression in rock art, body painting and sand drawing.

Beginning in the early 20th century, Aboriginal people in several locations minimally affected by European settlement were encouraged by anthropologists, missionaries and others to depict their stories in a more permanent form. In Arnhem Land, in the far north of Australia, painters developed an existing tradition of using natural ochres on bark stripped from trees, while in the desert regions of central Australia, acrylic paints on boards were used. Remarkably, these early paintings aroused international interest among institutions and collectors, not as cultural artifacts but as art. A critical step was the success of the *Dreamings* exhibition at the Asia Society, New York, in 1988.

Australian Aboriginal painting is now widely regarded as a serious form of modern art (McLean 2011, Petitjean 2010) with a strong visual impact. Aboriginal writer Djon Mundine describes an exhibition he curated in Dusseldorf in 1993 as follows: "Antjara was hung as a visual art show. It was supposed to generate a visual-emotional response; to engage the senses and the imagination" (Mundine 2013).

Although the visual impact of Aboriginal painting is often mentioned (Tuckson 1964, Ryan 1996, Coleman 2004). it has received surprisingly little analysis. As Ryan says, "most of the writings on Aboriginal art … tell us what it is about rather than why it compels the viewer as great art compels the viewer" (Ryan 1996, p. 128). An emphasis on "what it is about" is characteristic of anthropologists, who study Aboriginal art as an expression of cultural and spiritual themes (Berndt et al. 1982, Sutton 1988, Morphy 2010). In line with their focus on meaning, anthropologists have described Aboriginal painting "as having a more heavily conceptual than perceptual approach to

[1] A reprinted version of Barbara Gillam, "Figure-Ground and Occlusion Depiction in Early Australian Aboriginal Bark Paintings," *Leonardo*, Vol. 50, No. 3, pp. 255–267, 2017, reprinted courtesy of The MIT Press.

representation" (Sutton 1988, p. 36). Similarly, Morphy, the foremost expert on the art of the Yolngu peoples of Eastern Arnhem Land, says:

> Yolngu, rather than using techniques of visual representation to imitate the reality of the seen, are more concerned with conveying the reality of the unseen. In this respect, then, Yolngu art might also be deemed more conceptual than perceptual (Morphy 2007, p. 88).

Both authors deny that Aboriginal painting is "illusionistic," by which they seem to mean that it does not attempt to create an illusion of reality. While I fully acknowledge the conceptual and spiritual purpose of Aboriginal art, as a psychologist working in visual perception, I also see it as strongly perceptual in ways I describe here.

Despite stressing the essentially conceptual nature of Aboriginal painting, anthropologists nevertheless do mention visual features.[2] To understand the apparent paradox here, it is necessary to unpack what is meant by "perceptual." Traditional western art has tended to depict vistas; scenes receding into the distance as projected to a single viewpoint. To do this, Renaissance artists successfully analyzed the mathematics of linear perspective (Alberti 1435). When anthropologists say that Aboriginal art is more conceptual than perceptual, they seem to mean that it is not "perspectivistic" — it does not attempt to depict the projection of a scene from a single viewpoint nor even a single time frame. It does not attempt to simulate a retinal image of the real world. Although this is true, Aboriginal art is nevertheless perceptual. It depicts real-world properties and relations. Like all art, Aboriginal art draws on the responses of the human visual system, honed by evolution and experience to register properties of the environment relevant to our species. Cultural factors and skill determine just what aspects of visual experience are emphasized in any given art tradition, but all traditions must draw on a common repertoire of visual responses, and these go well beyond our ability to perceive 3D layout from linear perspective.

Aboriginal painting strongly emphasizes the ground, which is of paramount importance for hunter/gatherers. Ground is depicted both on a small and a large (even cartographic) scale, but usually as if below rather than receding from the observer (Berndt et al. 1982). Not surprisingly, the perceptual responses Aboriginal painting draws upon are those relating to perceiving figures, surfaces and locations (or their symbolic representatives) on or in the ground, interacting with one another and often overlapping (partially occluding) one another. Aboriginal painting uses occlusion relations rather than linear perspective to depict depth. It may also combine local perceptual effects to create visual impressions and conjunctions that could not exist in the real world.

Here I analyze the depiction of figure-ground relations and surface occlusion in early (mid-20th century) Aboriginal bark painting from "the classical period" (Sutton 1988, p. 36).

Unlike linear perspective, which has received a great deal of attention in the art history literature, the depiction of occlusion, although ubiquitous in painting, is surprisingly neglected (Kanizsa & Massironi 1989). These authors attribute this

[2] Morphy (2007) has drawn attention to the shimmer produced by *rarrk*, or cross-hatching, in Yolngu painting, as well as figure-ground reversals and other visual properties to be discussed later. Sutton (1988) discusses symmetry.

neglect to a misapprehension that occlusion relations are cognitive interpretations rather than immediate perceptual responses (Kahneman 2002). A similar view may account for anthropologists being aware of certain depictions of figure/ground relations in Aboriginal painting without considering them "perceptual."

The perceptual problem to be solved by painters is that an object or surface intended to appear partially behind another (i.e. partially occluded by it in the field of view) must accommodate the fact that the two surfaces will often be *adjoined* in a two-dimensional representation, sharing a common border. In real-world viewing, the depth cues of stereopsis and motion parallax are available to resolve the depth order of surfaces. However, a painter (or even a photographer) must use properties of the two-dimensional representation to create the impression that one of two adjoining surfaces is the foremost one and thus "owns" the common border and that the other surface does not end at the border but extends behind the front surface.

How can these impressions be conveyed in a painting with an immediate phenomenological (perceptual) impression of occlusion relations? This requires the skilled application of perceptual principles, which have been the subject of scientific study. These considerations apply to Aboriginal art, which as I shall show is very concerned with occlusion and depicts it with considerable sophistication and imagination. Figure 1 shows some quite early Aboriginal paintings that seem to have occlusion depiction as the major feature.

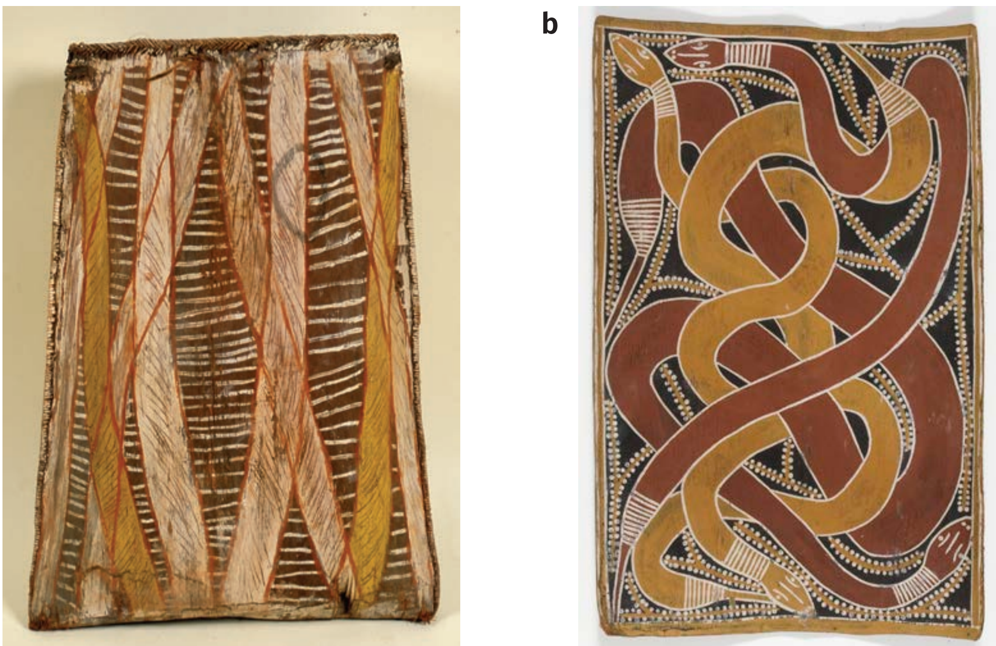

Fig. 1. Early bark painting featuring occlusion.
(a) *Water basket*, 1905, 69 × 38.5 × 29 cm, A338, South Australian Museum;
(b) David Malangi, *Serpent at Gatji waterhole*, 1969, 45.1 × 28.9 cm, MCA
(© Estate of the Artist licensed by Aboriginal Artists Agency Ltd.)

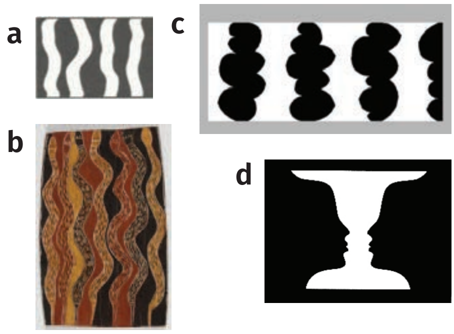

Fig. 2. Illustrating some figure/ground principles. (a) Parallel contours define figure; modelled after Metzger (1953); (b) Binyinyiwuy, *Rain snakes*, c. 1960, 41.5 × 26.4 cm, MCA (© Estate of the Artist licensed by Aboriginal Artists Agency Ltd.); (c) Convex areas tend to form figures with concave areas forming ground, modelled after Kanizsa & Gerbino (1976, pp 25–32); (d) Faces and vase alternate as figure, from Rubin (1915).

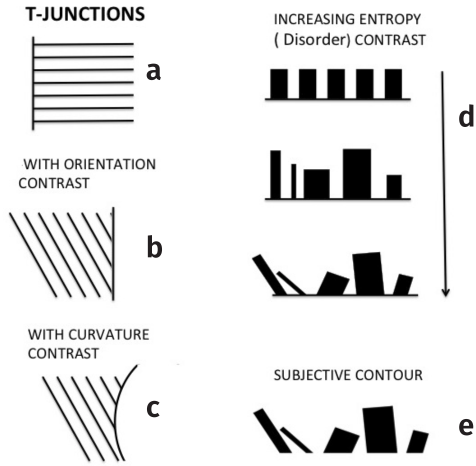

Fig. 3. Different arrangements of T-junctions. (a) "Top" orthogonal to stems; (b) "top" not orthogonal to stems; (c) "top" curved; (d) stems are disordered but with linear alignment; (e) as d but with a "subjective contour." Based on figures by Gillam & Chan (2002).

Scientific Studies of Occlusion

Psychologists have explored the perception of occlusion and border ownership in three major paradigms: figure-ground, occlusion at contour T-junctions, and amodal completion. These each reflect perceptual responses to different aspects of the ecological properties of occluding/occluded surfaces. I shall first briefly describe the effects revealed by these paradigms, then show how Aboriginal painting uses them, extends them and sometimes deliberately violates them.

Figure-Ground

The oldest form of perceived occlusion studied scientifically is figure-ground, first described by the Danish psychologist Edgar Rubin (1915). Using 2D drawings, Rubin juxtaposed black and white areas side by side with common borders between them (see Fig. 2).[3] He explored the 2D properties of an area that will increase the likelihood of it appearing to be the figure rather than the (back)ground. He found that areas whose shapes are symmetric, surrounded, predominantly convex and with parallel sides tend to be seen as figure, while adjoining areas that are asymmetric, surrounding, nonparallel and predominantly concave tend to be seen as ground (for examples, see Fig. 2). The figure takes ownership of the common border and has a shape determined by this border. The adjacent area, having lost the border, appears as background, extending behind the area seen as figure. The ground does not appear to have shape because it is not bounded. Two adjacent regions with balanced figural properties may alternate between figure and ground status (see Fig. 2d). Of relevance to later discussion, Peter-

[3] Figure-ground is a continuing focus of research on perceptual organization. (For a summary, see Wagemans et al. 2012). Rubin's principles have been confirmed and others added (e.g. Palmer & Ghose 2008).

a b

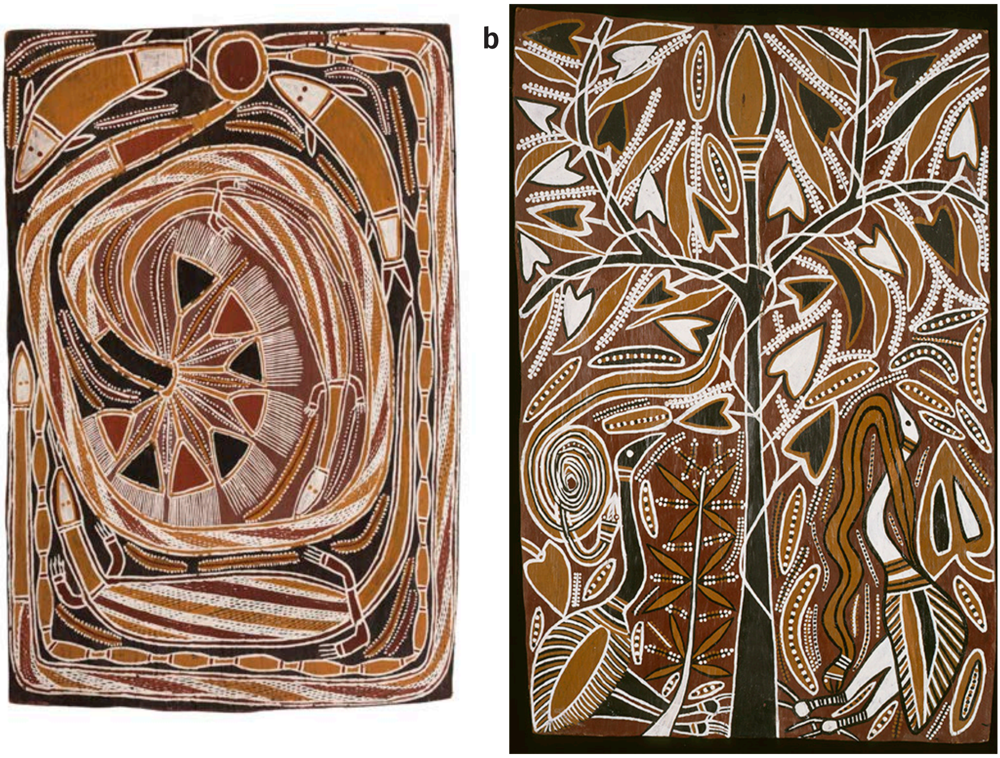

Fig. 4. Paintings from Central Arnhem Land.
(a) Dawidi, *Dhalngurr*, 1967, 54 × 78 cm, Museum and Art Gallery of the Northern Territory (© Estate of the Artist licensed by Aboriginal Artists Agency Ltd.);
(b) David Malangi, *The Hunter's Tree — Gurrmirringu, Ancestor*, 1965, 106 × 68.2 cm, State Art Collection, Art Gallery of Western Australia (© Estate of the Artist licensed by Aboriginal Artists Agency Ltd.).

son & Salvagio (2008) found that if the ground colour between successive convex shapes, like those in Fig. 2c, is varied, the figures dominance of those shapes is reduced.

Occlusion at T-junctions

Figure-ground research examines the *shape* factors that cause one area to take possession of a border and appear as a figure. However, shape is not the only factor that influences apparent occlusion. The boundary of an occluding surface often cuts off more remote contours forming "T junctions" at the intersection. The occluding surface edge forms the top of the Ts and the occluded contours form the stems (see Fig. 3a) (Ratoosh 1949, Rubin 2001).

T-junctions become much stronger occlusion cues when the line forming the top of the Ts is curved or when it is not at right angles to the stems (Gillam et al. 2014). This can be seen by comparing Fig. 3a with Figs 3b and 3c, and reflects the ecological fact that an edge cutting off a set of contours is more likely to be an occluding edge if it is unrelated to those contours. We use the terms "orientation contrast" and "curvature contrast" to refer to the cases shown in Figs 3b and 3c, respectively.

The sense of occlusion is also stronger for a line when it forms T-junctions with stems unrelated *to each other* in orientation, length, separation, etc., having high disorder (Gillam & Chan 2002, Gillam & Grove 2011) For example in Fig. 3d, the line along the bottom of the five shapes elicits an increasingly strong sense that it is occluding the shapes as their disorder (entropy) increases. This reflects the ecological fact that a set of unrelated objects are very unlikely to be aligned along a linear edge unless that edge is an occluding edge. We refer to this factor as "entropy contrast." Interestingly, the occlusion in Fig. 3d can be shown to be "perceptual" rather than "conceptual" by the observation (Gillam & Chan 2002) that a "subjective" occluding contour appears when the physical contour is removed (see Fig. 3e).

Amodal Completion and Relatability

Another common visual outcome of occlusion is that contours cut off by an occluding surface often continue on its other side. Such a continuation is usually accompanied by "amodal completion" or the apparent continuation of the interrupted contours behind the apparently occluding surface, even though the continuation is not sensorially present (Michotte et al. 1964). Amodal completion requires the two disjointed elements to be "relatable" (joinable by an uninflected curve) (Kellman & Shipley 1991).

Occlusion in Bark Paintings of Arnhem Land

Aboriginal bark painting has used all the principles described in the previous sections to varying degrees. Its interest for vision science derives from the innovative ways figure/ground and occlusion are depicted and manipulated to serve narrative and symbolic purposes.

Paintings with Minimal Occlusion

A number of early bark paintings, especially those from Western Arnhem Land, depict either a single figure or a number of separated figures on a single homogeneous ground (see supplemental Appendix 1; appendixes provided with online version of this article[4]). Overlap is almost entirely avoided in this tradition, which seems to be influenced by the rock art common in Western Arnhem Land. Because these paintings show little juxtaposition of surfaces or overlap, they are of limited interest for the study of occlusion.

Central Arnhem Land painters often cover the entire field with luxuriant details forming a complex, integrated organization with very little background visible. In the examples shown in Fig. 4, the contours of one form often follow the contours of another, so that there is minimal overlap. There are nevertheless subtle occlusion effects. In Fig. 4a, by Dawidi, a snake figure appears to bend out of and back into the picture, with its head becoming a sacred cabbage palm. The powerful sense that the palm is occluding something behind it is (unusually) based on its perspective bending rather than on T-junctions. Figure 4b, by David Malangi, is discussed by art historian Nigel Lendon, who points out the role of the tree as structural architecture and the presence of multiple vantage points in the painting, with some figures depicted in plane and some in elevation (Lendon 2004). Overlapping features, which Lendon also mentions, seem sparse, although the thin white occluding vine with its curvature contrast, reinforces and softens the rigid structural architecture of the tree. The subtle occlusion in this painting con-

[4] See the issue web page, at https://royalsoc.org.au/council-members-section/436-v152-2

trasts with the much bolder occlusion in the snake painting shown in Fig. 1b, also by Malangi.

Eastern Arnhem Land; Incorporating Clan Designs

The painting of the Yolngu people of Eastern Arnhem Land is particularly conducive to occlusion manipulation, because of its use of clan designs. These are repeating geometric patterns, which often form backgrounds as well as standing for a variety of features such as fire, sand hills or water. The two best-known clan designs are associated with different Yolngu kin groups, or moieties. The pattern of alternating vertical and horizontal strips is associated with the Dhuwa moiety (Fig. 5b), while the diamond-shaped honey design is associated with the Yirritja moiety (Fig. 5a). The honey design is especially conducive to figure-ground reversal. For example, on the upper left of Fig. 5a, the black diamonds alternate as figure with the lighter hourglass shapes.

All three aspects of occlusion perception studied by psychologists (figure-ground, contour junctions and amodal completion) play a role in the seminal paintings of Yolngu painter Mawalan Marika (circa 1908–1967) of the Dhuwa moiety. These factors will be discussed as they are used complementarily to create occlusion effects in a chronological succession of his paintings from 1941 up to 1958. Other paintings by Yolngu artists will be introduced where relevant. Of particular interest for perceptual psychology are the cases where Mawalan and others manipulate or violate the known "principles" of figure and ground. In some cases, the figureground impression nevertheless survives, while in other cases it seems to be deliberately destroyed.

Figure 5b shows one of Mawalan's paintings incorporating the Dhuwa clan design. On the left panel, the horizontal strips appear to occlude the vertical strips based on T-junctions and a degree of entropy contrast (the stems of the Ts outline surfaces with a variety of shapes that are cut off by a single linear contour). The goanna (lizard) on the right panel is seen as occluding the background strips, based on curvature contrast, convexity and the relatability of the horizontal contours across its body, giving a sense of amodal completion. Interestingly, the winding figure on the middle panel, which represents the goanna's track, also appears to occlude the background strips, even though they are not relatable across it. Curvature contrast between track and strips seems sufficient here to support the perception of occlusion without amodal completion.

Figure 6a, painted in 1946, is a more abstract painting in which vertical and horizontal strips are in a complex arrangement of textures and layers maintaining the orthogonal relationships of the clan design. It is difficult to imagine that Mawalan was not thinking of perceptual as well as narrative effects when arranging the textures and geometries for this picture. The whole composition gives an impression of complex depth layering based on nested T-junctions.

Mawalan's work in Fig. 6b, from 1948, is a tour de force of occlusion effects. It includes many examples of the clan design, largely using nonorthogonal components, so that orientation contrast adds a strong additional sense of occlusion. Furthermore, the snakes are perfect for giving a sense of occlusion by curvature contrast, since they are seen against backgrounds of linear contours. They also terminate a *variety* of contours, with entropy contrast enhancing the sense of

Fig. 5. Two major Yolngu clan designs (Eastern Arnhem Land).
(a) Munggurrawuy Yunupingu, *Lany'tjung story (Crocodile and Bandicoot)*, 1959, 193 × 72 cm, AGNSW (© Estate of the Artist licensed by Aboriginal Artists Agency Ltd.);
(b) Mawalan Marika, *Djang 'kawu at Yalangbara*, 1941, 102 × 53cm, Australian Museum (© Mawalan Marika/Copyright Agency). Note figure-ground reversal.

occlusion. But the really interesting innovation is the presence of nested occlusions (up to four layers of contours superimposed on each other by a succession of orientation contrasts [see lower left]). This produces not only a very strong impression of occlusion but also considerable depth.

The snakes in Fig. 6b suggest another novel perceptual effect. They are starkly black against a patterned surround. This gives them a sinister ambiguity, suggestive of either a figure or a hole or both at once. Figure 7a, by Gimindjo, shows even more clearly the tendency of a black region within

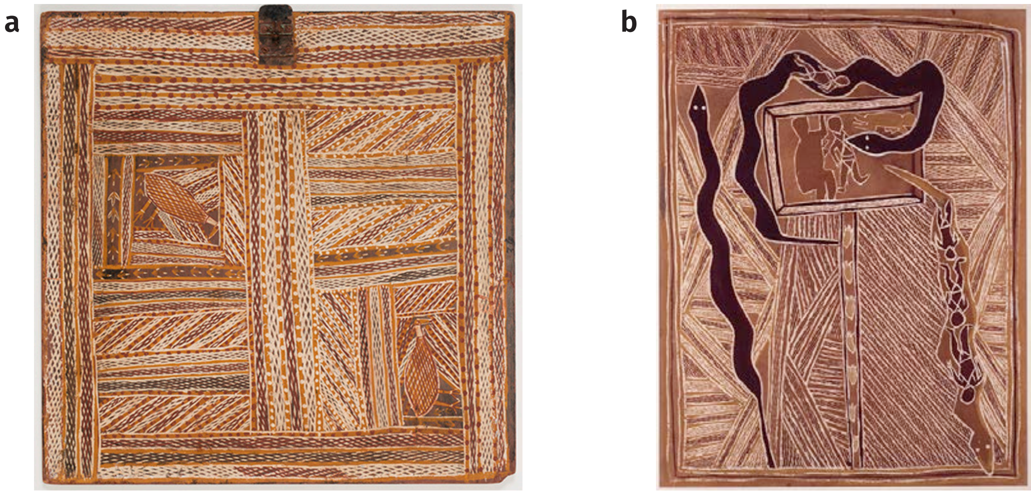

Fig. 6. Paintings by Marika with strong occlusion features.
(a) Mawalan Marika, *Yalanbara*, 1946, 45 × 45 cm, Macleay Museum (© Mawalan Marika/Copyright Agency);
(b) Mawalan Marika, *The Wagilag Sisters*, 1948, 56 × 42 cm, Kluge-Ruhe Aboriginal Art Collection (© Mawalan Marika/Copyright Agency

a context of texture to appear as a hole. The hole has considerable visual depth, presumably because of its lack of surface quality in contrast with the patterning of the surrounding ground. Gimindjo's painting also illustrates another feature of a number of bark paintings. The orientations of the bands of texture next to the snake change their angle systematically around its curved outline, as if dragged around by the snake's movement. Figure 7b, by Mawalan, shows similar changes in the orientations of background contours associated with the snake's changing curvature. In both cases, the lack of independence of the figure (the snake) and the pattern surrounding it militate against seeing occlusion by orientation contrast, although curvature contrast and texture differences are still present. Appendix 2 shows more examples of figure influencing ground.

Another Mawalan painting (Fig. 8a) shows another kind of relationship between figure and ground. The necks and tails of the goannas merge into the background strips. This is clearly symbolic of the belongingness of the goanna to the land and perhaps its tendency to be at least partially camouflaged by it. The goanna was also a clan totem for Mawalan. Morphy describes other examples of Yolngu painting in which figures merge with a design or become absorbed into it by *buwayak,* or the process of becoming invisible, for example by reproduction of the same design within the body of the figure and in the background outside (Morphy 2007).

A much later picture by Mawalan, *Hunting Scene* (1959) (Fig. 8b), depicts animals on various backgrounds. It is interesting that the scenes with buffaloes, which are introduced animals, have chaotic backgrounds, while the scenes with native animals have backgrounds that are more calm and orderly. This may be symbolic. The buffaloes are dangerous and disruptive in the context of

Fig. 7. Paintings in which the figure influences the ground.
(a) Gimindjo, *The Gadadangul snake*, 1960, 68.6 × 46 cm, MCA (© Estate of the Artist licensed by Aboriginal Artists Agency Ltd.);
(b) Mawalan Marika, *Wagilag Creation Story*, 1966, 116 × 40 cm. Courtesy Lauraine Diggins Fine Art (© Mawalan Marika/Copyright Agency).

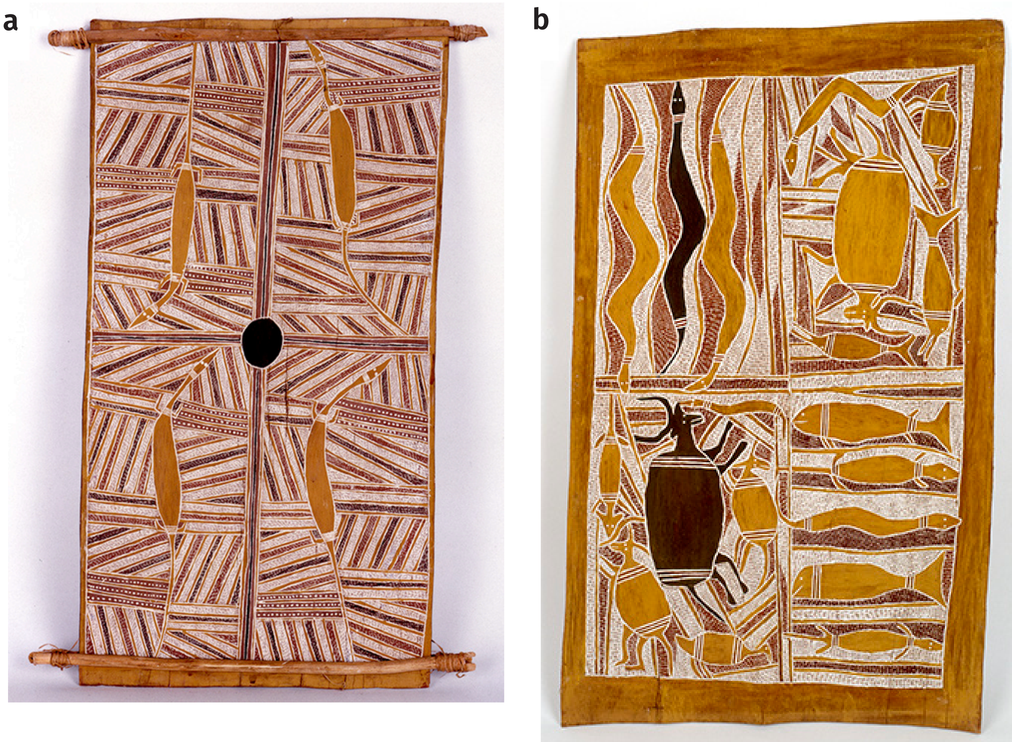

Fig. 8. Further paintings by Marika.
(a) Mawalan Marika, *Goannas at Yalangbara*, 1959, 73.98 × 40.64 cm, Kluge-Ruhe Aboriginal Art Collection (© Mawalan Marika/Copyright Agency);
(b) Mawalan Marika, *Bark painting (hunting scene)*, 1959, 102.9 × 62.3 cm, AGNSW (© Mawalan Marika/Copyright Agency). Panels with introduced animals (top right and bottom left) have chaotic backgrounds. Panels with native animals (top left and bottom right) have orderly backgrounds.

Aboriginal life and, unlike the native animals, move roughly across the terrain. The painting has another interesting detail. The snakes on the upper left appear as figure, while the irregular regions between them appear as ground, providing another example of E. Rubin's figural principle of parallelism (Rubin 2001). The goannas, sharks and snake in the panel at the bottom left all appear strongly as figures, even though the background changes its contrast polarity behind them (i.e. the background is darker on one side of the figure and lighter on the other). Clearly parallelism and convexity are sufficient here to support figure without continuity of background.

A later painting by Mawalan, *Tribesmen at Sea and Land* (Fig. 9a), is very different from his earlier paintings in that it totally disrupts figure and ground relations. The many and varied figures of people, boats and spears are strewn across the painting at various orientations. They do not occlude each other and are all the same light brown color. However, the background is not homogeneous as in earlier traditions of depicting

Fig. 9. Paintings with deliberately disordered ground.
(a) Mawalan Marika, *Tribesmen at sea and land*, 1958, 101.4 × 58 cm, MCA (© Mawalan MarikaCopyright Agency);
(b) Munggurrawuy Yunupingu, *Creation story*, 1970, 156 × 65 cm, NMWC, Utrecht (© Estate of the Artist licensed by Aboriginal Artists Agency Ltd.).

multiple figures demonstrated in Appendix 1. It is a chaotic mixture of irregular patches of black, dark brown and white with some patches attached to the figures and some not. The figures only become obvious after local scrutiny. By destroying the homogeneity of the ground, Mawalan has demonstrated a major advantage of a homogeneous ground in the depiction of a scene: It allows multiple figures to be seen more or less in parallel. Although Mawalan figures and patches of ground are much more varied in shape, size and orientation than those used by Peterson and Salvagio (2008), his disorder effect may be related to the effect of ground inhomogeneity shown in their (much later) studies. Figure 9b shows a less dramatic example of the background disorder effect, also by a Yolngu painter.

Layering in Aboriginal Bark Painting

An important feature of certain Western and Central Arnhem Land bark painting is the segregation of texture into two layers. This effect occurs as early as 1937 in a work by Yilkari Katani (Fig. 10). An arrangement of thin lines is superimposed on a coarser texture of crosshatched alternating dark

Fig. 10. Yilkari Katani, *Wagilag Sisters Dhawu*, 1937, 126 × 68.5 cm, Donald Thomson Collection (© Albert Djiwada)

and light areas. The patterns appear to segregate into two layers, with the fine lines appearing as a nearer grid through which the coarser pattern can be seen. Appendix 4 shows later, more compelling examples of segregation into layers. John Mawurndjul's painting (Appendix 3a), by comparison with Yirawala's (Appendix 3), suggests that segregation is enhanced when the coarser grid is relatable across the contours of the fine grid.

A later development enhances the spiritual effect of layering by combining it with a form of what Morphy (2011) refers to as "buwayak" in which low luminance contrast produces a ghostly appearance appropriate to the depiction of sacred ceremony and ancestral beings. Figure 11a, a much later painting by Katani, uses these combined effects to depict the Mayadin ceremony. The beings outlined by the thin lines tend to look transparent as well as ghostly so long as their inner texture has the same spatial frequency as the background. The central snake on the other hand looks ghostly without appearing transparent because it has a different spatial frequency from the background. The rainbow snake (Fig. 11b) by Mawurndjul shows a similar ghostly effect within a single figure, with the snake's internal outlines barely visible against a coarser cross-hatched texture. Mawurndjul is a master at depicting ancestral beings and ceremonies. In his painting in Appendix 5A the outlines of the rainbow snake are again almost camouflaged by lack of luminance contrast with the background of broader cross-hatching. One of the yawkyawk girls of the title (these are one such being) is partly absorbed within the snake by their common texture. Appendix 4B shows Mawurndjul painting his version of the Mayadin ceremony, with layering but without the ghostly effect of Katani's version (Fig. 11a), because of strong luminance contrast between the layers.

Occlusion Depiction with a Strong Conceptual Purpose

Figure 12a is another painting by Malangi, in which he manipulates figure and ground to create a polysemic effect. The pelican on the lower left is seen against a land background above and a sea background below. The background behind the figure changes for a semantic purpose without destroying its figural status perceptually.

Fig. 11. The fine/coarse layering effect combined with low luminance contrast to depict ancestral beings.
(a) Yilkari Katani, *Myth of the Wawilak Sisters*, before 1957, 39 × 78 cm, Museum der Kulturen, Basel (© Va 905);
(b) John Mawurndjul, *Ngalyod — the rainbow serpent*, 1985, 125 × 59 cm, AGNSW (© John Mawurndjul/Copyright Agency).

Figure 12b by Djunmal (1966) depicts forms of communication between the two moieties of the Yolngu people of eastern Arnhem Land and includes a rich mixture of occlusion effects. To the left is the clan design of the Yirritja moiety and to the right the design of the Dhuwa moiety. The middle crossing of the vertical strip dividing the moeties is fully modal, while the upper and lower crossings are amodal, with perceived completion occurring on the basis of contour relatability (despite a lack of texture relatability). These different forms of connection suggest both fully public and more private forms of communication between the moieties.

a

b

Fig. 12. Paintings in which conceptual meaning is linked to occlusion relationships. (See text for interpretations.)
(a) David Malangi, *The time of the dream*, 1965, 70.5 × 57 cm, MCA (© Estate of the Artist licensed by Aboriginal Artists Agency Ltd.);
(b) Djunmal, *The Djan'kava cross back to the mainland*, 1966, 187 × 54.5 cm (© Estate of the artist licensed by Aboriginal Artists Agency Ltd.) Courtesy National Museum of Australia;
(c) Jimmy Wululu, *Niwuda, Yirritja native honey*, 1986, 144 × 60 cm, NGA (© Jimmy Wululu/Copyright Agency).

Figure 12c by Wululu depicts the honey cells of his clan design but also refers at another level to a post-funeral ceremony in which the bones of the deceased are placed in a painted hollow log (depicted vertically in the centre of the painting) while the soul enters the ancestral realm (Cubillo & Caruana 2010). One diagonal passes behind the centre column, while the other diagonal passes in front of the column partly occluding it. These effects both depend on T-junctions and relatability. Arranging the edges of the diagonals to be in line with the diamonds within the column creates a certain tension between perceiving occlusion and non-occlusion. The carefully organized c

spatial relationships in this painting (characteristic of Wululu) undoubtedly relate to its ceremonial meaning.

Conclusion

Figure-ground and occlusion are skillfully depicted in Aboriginal bark painting. Perceptual principles known to psychologists, such as convexity, parallelism and contrast, are used in interesting ways, while novel effects, such as changing ground, disruption of ground, nested occlusions and texture layering, are explored. Although this was not their purpose, these paintings, like Rubin's (2001) demonstrations, have considerable heuristic value for scientists interested in the perception of occlusion.

I have also pointed to possible conceptual meanings specifically associated with the depiction of figure-ground and occlusion and their disruption. Even if one's interest in Aboriginal art is solely conceptual, a greater awareness of its visual meaning should enhance this appreciation.

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Thesis abstract

Efficient Hamiltonian Monte Carlo for large data sets by data subsampling

Doan Khue Dung Dang

Abstract of a thesis for a Doctorate of Philosophy submitted to The University of New South Wales, Sydney, Australia

Bayesian statistics carries out inference about the unknown parameters in a statistical model using their posterior distribution, which in many cases is computationally intractable. Therefore, simulation methods such as Markov Chain Monte Carlo (MCMC) and Sequential Monte Carlo (SMC) are frequently used to approximate the posterior distribution. SMC has the attractive ability to accurately estimate the marginal likelihood, although it is computationally more expensive than MCMC. Nevertheless, both methods require efficient Markov moves to deal with complex, high-dimensional problems. While Hamiltonian Monte Carlo (HMC) is a remedy in many cases, it also increases the computational cost of the algorithms appreciably, especially for large data sets. This thesis presents some novel methods that focus on speeding up inference by combining HMC and data subsampling. The first contribution is a Metropolis-within-Gibbs algorithm that successfully speeds up standard HMC by orders of magnitude in two large data examples. I then show that the new approach can be incorporated into other HMC implementations such as the No-U-Turn sampler. The next contribution is an extension of the first method to SMC for Bayesian static models, which gives comparable results to full data SMC in terms of accuracy but is much faster in several model settings. The final contribution shows that the subsampling HMC scheme can also be applied to a thermodynamic integration method to estimate the marginal likelihood.

Dr. Doan Khue Dung Dang

E-mail: doankhuedung.dang@unsw.edu.au

URL: https://www.dropbox.com/s/ynlqve0z84tqasz/thesis_2.pdf

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Thesis abstract

First impressions bias on sound sequence learning on multiple timescales: an order-driven phenomenon in auditory mismatch negativity

Jade D. Frost

Abstract of a thesis for a Doctorate of Philosophy submitted to The University of Newcastle, Callaghan, Australia

Humans are prone to systematic biases in perception that impact rationality in judgement. First-impression bias occurs when judgement is overly affected by information presented during an initial encounter. Using the amplitude of a specific brain response, the mismatch negativity (MMN), our team discovered that the brain is prone to this bias effect during the very early stages of sound-sequence learning preceding knowing awareness. In our research program, we aim to determine which experimental conditions expose or modify first-impression bias effects on sound-pattern learning on multiple timescales. Predictive coding models assume the brain is hierarchically organised and uses perception to make inferences about the sensory world whilst updating predictions about incoming sensory information. Recurring comparisons between bottom-up input and top-down predictions consider environmental noise, and determine the inferential modelling process. MMN, an event-related response evoked by violating regularity in a structured sound sequence, is an example of a prediction error signal. Its presence informs on prediction model content whereas its amplitude informs on model confidence (or precision). Prediction error amplitude to a pattern violation is largest when model confidence is very high and may require engagement of additional, higher-order resources. First-impression bias shows that the network uses contextual information at sound sequence onset to modulate MMN amplitude to probabilistic changes thereafter. Our data show that first-impression bias is a remarkably robust and long-lasting phenomenon that can be interrupted if participants undertake an attention-demanding task whilst hearing multi-timescale sequences or are provided with accurate foreknowledge about sound structures before sequence exposure. In interpreting these data, we discuss how models assuming only local sound probabilistic information drives the MMN-generating process cannot explain bias effects on MMN amplitude. Rather, the bias is a striking example of a hierarchical inference process incorporating attentional resources that considers the potential relevance of sound information and its stability over time.

Dr Jade Frost
Faculty of Science
The University of Newcastle
Callaghan NSW 2308
AUSTRALIA

E-mail: jade.frost@newcastle.edu.au

URL: http://hdl.handle.net/1959.13/1387378

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Thesis abstract

The rôle of mitochondrial DNA in the post-injury inflammatory response following major trauma

Daniel McIlroy

Abstract of a thesis for a Doctorate of Philosophy submitted to The University of Newcastle, Callaghan, Australia

Trauma is the leading cause of death in the developed world in those aged under 45 years. The main potentially modifiable cause of late death after injury is post-injury multiple organ failure (MOF). Early MOF is characterised by a lethal combination of systemic inflammatory response syndrome (SIRS) which is underpinned by neutrophil proliferation and "priming" as a result of the initial injury and haemorrhagic shock. If primed neutrophils are then exposed to a "second hit" then dysregulated neutrophil-driven inflammation can occur, resulting in end organ sequestration, parenchymal damage, MOF and ultimately death. Interest has increased in endogenous drivers of the innate immune system that exert a potent pro-inflammatory effect by activating pathogen recognition receptors (PRRs), which are designed to respond to pathogen associated molecular patterns (PAMPs) found in bacteria. Endogenous factors that can trigger this response in the absence of sepsis have been termed "alarmins" or damage associated molecular patterns (DAMPs). Mitochondrial DNA (mtDNA) is a potently pro-inflammatory DAMP, which has been found to be highly elevated in the post-injury state. Mitochondrial DAMPs have also been associated with neutrophil-mediated end organ injury.

The primary aim of this thesis was to characterise the effect of post-injury non-life saving orthopaedic surgery on circulating mtDNA levels. No study had looked at the effect of surgical intervention on levels of mtDNA after initial injury and possible sources of mtDNA release. Initially a pilot study of 35 trauma patients who subsequently underwent orthopaedic surgery was performed, primarily measuring cell-free mtDNA and nuclear DNA (nDNA) with sequential plasma measurements over a 5-day perioperative period with comparison to 20 healthy control subjects. mtDNA levels continued to rise over the 5-day observation period following surgery and had no correlation to markers of cell-necrosis either in the form of direct musculoskeletal injury, or secondary inflammatory end organ injury. Whilst nDNA levels were elevated when compared to healthy controls, no increase was observed in the 5-day observation period. Elevated mtDNA perioperative levels were directly correlated with the magnitude and early timing of surgical intervention. mtDNA levels were inversely proportional to the volume of crystalloid infused, indicating a possible rôle for adequate resuscitation in modulating circulating mtDNA levels. A positive trend between mtDNA levels and incidence of post-injury SIRS and MOF was observed, but this failed

to reach statistical significance. This led to the genesis of the hypothesis that the persistently elevated mtDNA levels may have a primary inflammatory source.

The secondary aims of this thesis were threefold. Firstly, to determine whether there was a primary inflammatory source of mtDNA, namely focusing on possible neutrophil extracellular trap (NET) formation or "NETosis". Secondly, to determine what factors may propagate and influence mtDNA release. Finally, to investigate mechanisms for modulating circulating mtDNA levels following injury and subsequent surgery by looking at DNase activity. NETosis is characterised by the release of chromatin in conformational net-like structures in response to sepsis, however some authors had shown that under certain conditions NETs could be composed of mtDNA (mtDNA-NETs). The next study performed focused on demonstrating whether NETs were formed after injury and subsequent surgery and what type of DNA they were composed of. The presence of NETs had been postulated after traumatic injury by one group based on observed high concentrations of cell-free DNA but they failed to define any microscopic evidence of NET formation. In our next paper we definitively demonstrated that NETs were formed after injury and subsequent surgery and also in response to elective orthopaedic hip replacement surgery. This was achieved microscopically using fluorescent DNA avid dyes to demonstrate the presence of conformational DNA-NET structures. Molecular genetic analysis of the NETs formed in response to injury and subsequent surgery or in response to elective surgery alone revealed that the NETs were mtDNA-NETs. Due to molecular similarities between mtDNA and bacterial DNA (bDNA) we hypothesised that mtDNA might trigger NETosis through a PRR mediated pathway. In the next paper we studied the effect of exposing healthy neutrophils and post-injury perioperative neutrophils to physiological concentrations of mtDNA we had measured in our initial pilot over the 5-day observation period. We then conducted a series of positive control experiments using phorbol myrisate acetate (PMA), a known potent stimulator of NETosis. NETs were triggered after trauma and healthy neutrophils were exposed to mtDNA. Notably the NETs formed in response to mtDNA were mtDNA-NETs in both trauma and healthy neutrophils, however trauma neutrophils were less responsive compared to healthy control neutrophils. This observation was thought to be possibly due to the exposure of trauma neutrophils to high levels of mtDNA after injury and surgery causing prior mtDNA-NET production. NETs formed in response to PMA exposure were composed almost exclusively of nDNA (nDNA-NETs). Finally, we studied the plasma activity of DNase alongside mtDNA and nDNA concentrations in a much larger cohort of trauma patients (n=103) compared to our initial pilot (n=35). Circulating DNase isotypes are responsible for the digestion of extracellular DNA whether mtDNA or nDNA and also digest NETs. DNase activity was significantly reduced compared to that measured in healthy controls. This greater powered study did reveal a statistically significant positive correlation between perioperative mtDNA levels and SIRS but not MOF, despite a strong trend.

Our data suggest that after traumatic injury, the timing/magnitude of surgery and adequacy of resuscitation influence the levels of circulating mtDNA. Neutrophils contribute a significant amount of mtDNA through mtDNA-NET formation in the post-injury and perioperative period. mtDNA can essentially drive its own release through a positive feedback loop. This occurs through circulating mtDNA triggering further mtDNA-NET release, resulting in a vicious cycle of dysregulated inflammation and associated SIRS with a likely link to post-injury MOF. Most excitingly the finding of reduced DNase levels in the face of high mtDNA levels. This may offer up a novel therapeutic target for modulation of aggressive post-injury SIRS, through the potential administration of exogenous DNase in the post-injury and peri-operative recovery period.

Dr Daniel McIlroy
Faculty of Health and Medicine
The University of Newcastle
Callaghan NSW 2308
AUSTRALIA

E-mail: dan_mcilroy@hotmail.com

URL: http://hdl.handle.net/1959.13/1389042

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Thesis abstract

On "being first:" reconsidering Australian higher education equity policy through a comprehensive analysis of the aspirations of prospective first-in-family students

Sally Patfield

Abstract of a thesis for a Doctorate of Philosophy submitted to The University of Newcastle, Callaghan, Australia

In the pursuit of greater equity and expanded access to higher education, a discourse of widening participation has been foregrounded within the Australian higher-education sector in recent decades. This agenda has largely focused on moving towards proportional representation for six equity target groups that have been inscribed within policy for more than 25 years: people from low socioeconomic status backgrounds, people from regional and remote areas, people with disabilities, people from non-English-speaking backgrounds, women in non-traditional areas of study, and Indigenous people. While the higher-education landscape has transformed over this period, these groups remain core to conceptualisations of equity within policy and practice, fundamentally shaping how educational inequalities can — and should —be addressed.

This thesis contributes to current debates calling for reform of the national higher-education equity framework by investigating a group of students who have received comparatively little attention within the widening participation agenda and the Australian context more broadly — students who would be "first in family" (FiF) to hold a university-level qualification. Drawing on data collected as part of a four-year longitudinal project (2012–2015), this mixed-methods study augments policy interest in school students' aspirations, as part of the widening participation agenda, by focusing on *prospective* FiF students (aged 8–18 years) enrolled in primary and secondary government schools in New South Wales. Moving beyond the simplistic notion of "raising aspirations" that has been embedded within this agenda, a sociological lens was used to frame the study, with Arjun Appadurai's theory of the "capacity to aspire" and Pierre Bourdieu's concepts of "capital," "habitus," and "field" utilised to develop a theoretically informed understanding of access to higher education for prospective FiF students. Quantitative data in the form of annual online surveys completed by students (n = 6,492; categorised as prospective FiF or non-FiF) from 64 schools were linked with socio-demographic and prior academic achievement records, in order to establish a portrait of prospective FiF students and their educational aspirations. Qualitative data in the form of focus groups conducted in a subsample of 30 schools were utilised to gain a deeper understanding of the formation of aspirations for university among prospective FiF students (n = 198).

Collectively, these data challenge existing policy by showing that FiF status constitutes a distinct equity category. While my

analysis demonstrated that many prospective FiF students had overlapping sociodemographic characteristics with one, or a number of, the existing equity target groups, FiF status did not simply overlap these categories. Specifically, prospective FiF students were more likely to identify as Indigenous and come from lower socioeconomic status backgrounds in comparison to their non-FiF peers. However, FiF students were more likely to come from English-speaking backgrounds, which is in contrast to the equity policy focus on students from language backgrounds other than English. In addition, some prospective FiF students did not fit into any of the existing equity categories at all.

Moreover, my analysis illuminated the nature of FiF status beyond its relationship with the existing equity target groups. Overall, non-FiF students were more likely to aspire to university in comparison to prospective FiF students at all year levels covered in the study (Years 3–12 inclusive), even when taking into account factors such as those defining the existing equity groups, and measures of academic achievement. Many of the prospective FiF students who aspired to university faced limited access to knowledge of higher education within their families, with their parents imparting support and advice through the promotion of values and attitudes. In addition, the capacity to aspire to higher education varied *among* prospective FiF students depending on the capital they could access and deploy via their familial and non-familial networks, which in turn brought some students closer to higher education.

Given this analysis, I argue that FiF status should be recognised within higher-education policy and practice as discrete from the existing equity categorisations. My study draws attention to ways in which school students who are "first" in their families to pursue higher education may need extra support. Greater recognition of this population of students must not only occur once they have arrived at university, but also during the period of early aspiration formation over the course of primary and secondary schooling. My study brings to light this period as an important juncture for supporting prospective FiF students, with schools and universities playing a critical role in informing, nurturing, and resourcing aspirations, and thus facilitating pathways into higher education.

Dr Sally Patfield
Faculty of Education and Arts
The University of Newcastle
Callaghan NSW 2308
AUSTRALIA

E-mail: sally.patfield@newcastle.edu.au

URL: http://hdl.handle.net/1959.13/1388189

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Thesis abstract

Quantum emission from hexagonal boron nitride

Trong Toan Tran

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Technology Sydney, Sydney, Australia

Realization of quantum technologies demands successful assembly of crucial building blocks. Quantum light sources, lying at the heart of this architecture, have attracted a great deal of research focus during the last several decades. Optically active defect-based centres in wide bandgap materials such as diamond and silicon carbide have been proven to be excellent candidates due to their high brightness and photostability. Integration of quantum emitters on an on-chip integrated circuit, however, favours low dimensionality of the host materials. In this thesis, we introduce a class of novel quantum systems hosted in hexagonal boron nitride (hBN) — a wide bandgap semiconductor in the two-dimensional limit. We demonstrate that the quantum systems possess a record high single photon count rate, exceeding 4 megahertz at room temperature, extremely high stability under high excitation at ambient conditions, and fully linear polarized emission. Spin-resolved density functional theory calculation suggests that the defect centre is an antisite nitrogen vacancy. Furthermore, we demonstrate engineering of quantum emitters from hBN by a range of nanofabrication techniques and that resonant excitation of the emitters is achievable. Coupling of quantum emitters in hBN to plasmonic particle arrays is also demonstrated, showing several times the Purcell enhancement factor.

Dr Trong Toan Tran,
School of Mathematical and Physical Sciences,
Faculty of Science,
University of Technology Sydney,
Sydney NSW 2007
AUSTRALIA

E-mail: trongtoan.tran@uts.edu.au

URL: https://opus.lib.uts.edu.au/handle/10453/125170

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Obituary

Ann Veronica Helen Moyal
AM, FRSN, FAAH

23 February 1926–21 July 2019

Ann's mother named her after the heroine of H.G. Wells' scandalous novel of a rebellious New Woman — and, though both mother and father raised her in the comfortable respectability of Sydney's North Shore, Ann broke many barriers.[1]

Upon graduating in 1946 with first-class honours in history from the University of Sydney, Ann Hurley worked as a research assistant for W. C. Wentworth (then gathering information on communists) and John Carrick (research officer for the New South Wales branch of the Liberal Party). A scholarship took her to the University of London in 1949, but she soon abandoned postgraduate research to work for Nicholas Mansergh at the Royal Institute of International Affairs and then Max Aitken, Lord Beaverbrook, whom she helped write his recollections of *Men and Power, 1917–1918* (1956) in the British government during the Great War.

Ann would return to academic employment, but never for long. At the ANU from 1959 to 1962 she laid the foundations of the *Australian Dictionary of Biography*, while the two titular editors, Manning Clark and Malcolm Ellis, did combat, and then worked with Earle Page on his memoirs, *Truant Surgeon* (1963). As a joint research associate of the Research School of Social Sciences and the Academy of Science, she produced a *Guide to the Manuscript Records of Australian Science* (1966) and embarked on a biography of the colonial geologist (and founder of the Royal Society), W. B. Clarke. A book of documents on *Scientists in Nineteenth-Century Australia* (1975) appeared subsequently. By this time she had accompanied her third husband, the mathematician José Enrique Moyal, to the Atomic Energy Laboratory in Illinois and, while working as science editor for the University of Chicago Press, she published an arresting article on the problems of the Argonne laboratory.

In 1971 Ann took up a lectureship at the NSW Institute of Technology (now UTS), from where she produced an equally stringent account of the mismanagement of the Australian Atomic Energy Commission. By this time her interest in the history of science extended to science policy and she had a spell at the celebrated Science Policy Research Unit at Sussex University. Her appointment to Griffith University in 1976 was to direct the Social Policy Research Centre at Griffith, an arrangement that broke down during 1979 in an acrimonious dispute over her impossible teaching burden. Never cowed by authority, Ann was disconcerted by the way her academic colleagues bowed to its misuse. For the rest of career she would work as an independent scholar.

She did so at first as an associate of Henry Mayer's department of politics at the University of Sydney. Mayer, a restless and irreverent polymath, encouraged her

[1] Ann Moyal was the inaugural winner of the RSNSW History and Philosophy of Science Medal in 2014. The late poet, Les. A. Murray, dedicated his 1993 poem, "The Tube", to her. [Ed.]

to accept a commission to write a history of telecommunications in Australia. *Clear Across Australia* (1984) met with acclaim, and deservedly so for it integrated the technological dimensions with the role of government, the men and women who staffed the Postmaster-General's Department and the profound effects of telecommunications on Australian life.

In the course of this project Ann moved with her husband to Canberra, where she became editor of the ANZAAS bimonthly journal, *Search*. It was here also that she produced *A Bright & Savage Land: Scientists in Colonial Australia* (1987), two striking works of natural history, *Platypus* (2001) and *Koala* (2006), and an edited edition of W. B. Clarke's correspondence, *The Web of Science* (2001). A visiting scholar in several university departments, she was profoundly out of sympathy with the changes made to universities in the 1990s, from which a number of her friends resigned, and with the assistance of Warren Horton, then Director-General of the National Library, she established the Independent Scholars Association. Ann made the Petherick Room of the National Library her base of operations and used its manuscript collections to write a brief and compelling life of *Alan Moorehead* (2005), the journalist, biographer and historian whose life as a writer reaching a popular audience exemplified her ideal of the independent scholar.

There were other works that appeared in this final phase of Ann's life, including a biography of her third husband, *Maverick Mathematician* (2006). Her own volume of memoirs, *Breakfast with Beaverbrook* (1995) carried the subtitle "Memoirs of an Independent Woman," and ranged memorably across her adventures. A later volume, *A Woman of Influence: Science, Men and History* (2014), took up particular aspects of her dealings with all three. Her range of friendships was large, and to the end she kept them up, curious, encouraging and supportive.

Ann Moyal was a Fellow of the Royal Society of New South Wales (and contributed articles to its *Journal & Proceedings* right up to 2019) and the Australian Academy of the Humanities, and was awarded honorary doctorates by the ANU and the University of Sydney. She was appointed a Member of the Order of Australia in 1993 for her "contribution to the history of Australian science and technology, especially the writing of its history." That citation understates her achievement, as does the level of her honour. She was a path-breaker who worked across domains of knowledge, an exceptionally intelligent woman with unshakeable principles.

— Professor Emeritus Stuart Macintyre, AO, FAHA, FASSA

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[2] E. Mozley was her second husband.

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Proceedings of the Royal Society of New South Wales
The 2019 programme of events — Sydney

Held at the State Library of NSW (SLNSW), Shakespeare Place, Sydney; Sydney Mechanics' School of Arts (SMSA), 280 Pitt Street, Sydney or otherwise stated.

Wed 6 Feb	1270th Ordinary Meeting 2018 RSNSW Scholarship winners, at SLNSW; 3MT presentation	Fiona McDougall, Macquarie University	Human-associated bacteria and antibiotic resistance in grey-headed flying foxes
		Evelyn Todd, University of Sydney	Using genetics to improve athletic performance in thoroughbred horses
		Mr Chuhao Liu, University of Wollongong	Finding the best-fitting jeans for railway foundations
Mon 25 Feb	Annual Meeting of the Four Societies 2019	Helen Cook, GNE Advisory	Legal considerations pertaining to nuclear energy as an option for Australia
	Held in conjunction with the Nuclear Engineering Panel of the Sydney Branch of Engineers Australia, the Australian Nuclear Association and the Australian Institute of Energy. Held at Allens.		
Tue 26 Feb	SMSA/RSNSW Speaking of music, lecture 1 at SMSA	Dr. Wesley J. Watkins IV, Jazz and Democracy Project	Jazz and democracy
Wed 6 Mar	1271st OGM and open lecture at SLNSW	Katherine Belov, School of Life and Environmental Sciences, University of Sydney	Using genomics to conserve Australia's biodiversity
Thu 21 Mar	SMSA/RSNSW Women and Science, lecture 1 at SMSA	Suzanne Burdon	Mary Shelley, scientist, and Frankenstein
Wed 3 Apr	1272nd Ordinary Meeting and 152nd Annual General Meeting at SLNSW	Emeritus Professor Brynn Hibbert, School of Analytical Chemistry, UNSW	Measuring what we can: or how to lose weight on May 20th
Thu 2 May	SMSA/RSNSW Women and Science, lecture 2, at SMSA	Susannah Fullerton OAM FRSN	Ada Lovelace, without whom we might not have computers

Fri 10 May	Annual Dinner: Distinguished Fellow's Lecture and presentation of the Society's 2018 awards, at Swissôtel	Guests of honour: The Society's Vice-Regal Patron, Her Excellency The Honourable Margaret Beazley AO QC, Governor of NSW and Michelle Simmons FRS FAA FTSE DistFRSN Australian of the Year 2018 ARC Laureate Professor Scientia Professor of Physics, UNSW	The new field of atomic electronics
Wed 5 Jun	1273rd Ordinary Meeting at SLNSW	Dr Kate Faasse School of Psychology UNSW	This talk may cause side effects: nocebo effects in medicine
Thu 20 Jun	RSNSW/SMSA Women and science: lecture 3, at SMSA	Professor Lesley Hughes FRSN Dept. of Biological Sciences Macquarie University	Climate change and our life support system
Wed 3 Jul	1274th Ordinary Meeting at SLNSW	Emeritus Professor Robert Burford FRSN UNSW	Past, present and future of polymers: is the plastics age over?
Mon 23 Jul	RSNSW/SMSA Women and science: lecture 4, at SMSA	Emerita Professor Barbara Gillam FASSA FRSN School of Psychology, UNSW	Visual perception in Aboriginal art
Wed 7 Aug	1275th Ordinary Meeting at SLNSW	Professor Peter Shergold AC FRSN, Chancellor, Western Sydney University	Democracy under challenge: how can we restore a sense of citizenship?
	National Science Week (NSW) talks held at SMSA.		
Mon 12 Aug	NSW talk 1	Dr Ragbir Bhathal FRSN	Aboriginal astronomy
Tues 13 Aug	NSW talk 2	Emeritus Professor Robert Clancy AM FRSN	Unexpected results — Australian science to 1950
Thu 15 Aug, 12:30	NSW talk 3	Dr Josh Harle	Machine aesthetics of the human body
Thu 15 Aug, 18:30	NSW talk 4	Professor Mikhail Prokopenko FRSN, University of Sydney	Computer modelling of epidemics

Wed 14 Aug	Poggendorff lecture at University of Sydney	Professor Robert Park School of Life and Environmental Sciences University of Sydney	Cereal killers: how plant diseases affect food security
Fri 16 Aug	UNSW Centre for Ideas event, the inaugural Gerald Westheimer Lecture	Professor Elizabeth Blackburn AC FAA FRS DistFRSN Dept. of Biochemistry and Biophysics, UC San Francisco	The telomere effect
Wed 4 Sep	1276th Ordinary Meeting at SLNSW	Professor Hans Pols FRSN Head, School of History and Philosophy of Science University of Sydney	Physicians as public intellectuals: Indonesian physicians in the Dutch East Indies
	3MT presentation	Miss Lingzhi Kang, University of Wollongong	Biofabricated platforms for wound healing and skin regeneration
Thu 19 Sep	Sci-Fi Series — The future is here, at the National Maritime Museum	Professor Emma Johnston AO, Dean of Science, UNSW Sydney, RSNSW Clarke Medal Recipient	The Flying Eyes: How ecologists are using new technology to see hidden worlds
		Professor Andy Pitman, Director, ARC Centre of Excellence for Climate Extremes	The day after tomorrow: What does climate change mean for us?
		Associate Professor Tracy Ainsworth, Scientia Fellow, Centre for Marine Science & Innovation, UNSW	Deep Blue Sea: Solving the coral reefs crisis
Mon 23 Sep	RSNSW/SMSA Women and science: lecture 5, at SMSA	Anne Harbers	Electricity, astronomy, and natural history: from colonial Sydney to Royal Sweden, and a ladies' academy of science in between
Wed 2 Oct	1277th Ordinary Meeting at SLNSW	Professor Peter Godfrey-Smith The University of Sydney	Bodies and minds in animal evolution
Thu 17 Oct	RSNSW/SMSA Women and science, lecture 6, at SMSA	Susan Pond AM FTSE FAHMS FRSN	Women at the frontiers of biotech
Wed 6 Nov	1278th Ordinary Meeting at SLNSW	Professor Herbert Huppert FRS FRSN University of Cambridge	The Beginning of Weather Forecasting: Matthew Maury, Robert FitzRoy FRS, and L. F. Richardson FRS

Thu 7 Nov	RSNSW and Four Academies Forum, Government House, Sydney	Hosted by Her Excellency The Honourable Margaret Beazley AO QC, Governor of NSW and Patron of the Royal Society of NSW	Making SPACE for Australia
	Held in cooperation with the Australian Academy of Science, the Australian Academy of Technological Sciences and Engineering, the Australian Academy of the Humanities and the Academy of Social Sciences in Australia.		
Tue 12 Nov	Joint AIP, RSNSW, and RACI Open Lecture 2109, at UTS	Professor Jodie Bradby ANU	Diamonds and high pressure physics
	Held in conjunction with the Australian Institute of Physics, RSNSW and the Royal Australian Chemical Institute.		
Thu 21 Nov	RSNSW/SMSA Women and science, lecture 7, at SMSA	Emerita Professor Ann Green FTSE FASA FAIP FRSN	An accidental astronomer
Wed 5 Dec	1279th Ordinary Meeting followed by the Society's Christmas Party at SLNSW	Royal Society of NSW 2019 Jak Kelly Award: Gayathri Bharathan, Macquarie University	All-integrated mid-infrared laser sources

The 2019 programme of events — Southern Highlands

Held at the Mittagong RSL, 1st Floor, Joadja/Nattai Rooms.

Thu 21 Feb	Prof Rodney Croft The Australian Centre for Electromagnetic Bioeffects Research (ACEBR)	The Effect of Non Ionisation Electromagnetic Radiation on our Health
Thu 21 Mar	Susannah Fullerton OAM Author. President of the Jane Austin Society of Australia. Patron of the Rudyard Kipling Society of Australia	The Life and Diary of Samuel Pepys.
Thu 18 Apr	Prof Richard Kemp UNSW School of Psychology	Psychology of Eyewitness Memory
Thu 16 May	Dr Damian Wrigley ANU Botanical Gardens	The Importance of a Seed Bank in Future Preservation of Plant Species
Thu 20 Jun	Prof Ken Baldwin Director of the Energy Change Institute at ANU. Deputy Director of the Research School of Physics and Engineering.	Nuclear Energy
Thu 18 Jul	Dr Christian Heim and Dr Caroline Heim	Understanding the Mental Health Crisis and how your Relationships can save you
Thu 15 Aug	Prof Rick Shine AM School of Life and Environmental Sciences, Uni of Sydney	Sequencing the Cane Toad Genome (DNA)
Thu 19 Sep	Dr Rebecca Carey Volcanologist, Senior Lecturer Earth Sciences, University of Tasmania	Volcanology
Thu 17 Oct	Dr Ian Bryce Rocket Scientist and Ethics Teacher	The Physics of the Mind: Exploring sentience, freewill, and morality
Thu 21 Nov	Dr Steven Harrison	Porcelain through History — Discoveries and analyses of ancient porcelain from around the world

The 2019 programme of events — Hunter Branch

Wed 9 Oct	Inaugural Meeting, Hunter Branch of the Royal Society of NSW, and open lecture, at the Newcastle Club	Professor Hugh Durrant-Whyte FRSN, NSW Chief Scientist and Engineer	Industries of the Future

Awards 2019

1) James Cook Medal 2019 — Scientia Professor Matthew England

The James Cook Medal is awarded from time to time for outstanding contributions to both science and human welfare in and for the Southern Hemisphere.

Professor Matthew England, of the UNSW Climate Change Research Centre, is recognised as one of the world's foremost experts in how the world's oceans control regional and global climate on time scales from seasons to millennia. His field of research spans physical oceanography and climate dynamics, where he has written seminal papers on Southern Ocean water-mass formation, Antarctic ocean-atmosphere-ice interactions, climate modes of variability, and ocean ventilation processes. Importantly, in the context of the James Cook Medal, England has a sustained track record of outstanding research and discovery in areas that make an impact on human welfare, both here in Australia and across other regions of the Southern Hemisphere, including improved predictions of rainfall and climate variability, discoveries of the oceanic drivers of severe drought and flooding rains, and quantification of the impacts of climate change and the fate of ocean pollution.

2) Edgeworth David Medal 2019 — Professor Si Ming Man

The **Edgeworth David Medal** is awarded each year for distinguished research by a young scientist under the age of 35 years for work done mainly in Australia or for contributing to the advancement of Australian science.

Professor Si Ming Man, of the John Curtin School of Medical Research at the Australian National University, is an outstanding young researcher in the field of innate immunology, attaining a full professorship only six years after his PhD graduation. Six of his recent papers are recognised as "highly cited," being in the top 1% of the field. His research has identified a class of disease-fighting "killer" proteins, produced by the cell, which can directly attack bacteria, causing these pathogens to die and release signals that can rapidly trigger activation of the immune system. Further studies have shown that immune receptors have critical roles in preventing gut inflammation and the development of colorectal (bowel) cancer, while most recently he has discovered that toxins from foodborne bacteria can be detected and blockaded by immune receptors to prevent sepsis.

3) Clarke Medal for Geology 2019 — Professor Dietmar Müller

The **Clarke Medal** is awarded each year for distinguished research in the natural sciences conducted in the Australian Commonwealth and its territories. The fields of botany, geology, and zoology are considered in rotation. For 2019, the medal was awarded in Geology.

Professor Dietmar Müller, of the School of Geosciences at the University of Sydney, is internationally renowned for discoveries that have transformed our fundamental understanding of the Earth's evolution, environments and geological resources. Many of these discoveries were made possible only through Müller's international research efforts in building a Virtual Earth Laboratory to "see" deep into the Earth in four dimensions (space and time), opening up the Earth's dynamic history going back 200 million years. His scientific discoveries are outstanding, with contributions to the field including age and tectonic evolution of the ocean basins, earthquake hazard mapping, Australia's intraplate stress through time, sea floor image analysis, the evolutions of continental basins and margins, and linking plate tectonics and mantle convection to Australia's surface topography through time.

4) History and Philosophy of Science Medal 2019 — Professor Evelleen Richards

The **Society's History and Philosophy of Science Medal** is awarded each year for outstanding achievement in the History and Philosophy of Science, especially the study of ideas, institutions, and individuals of significance to the practice of the natural sciences in Australia.

Professor Evelleen Richards, an Honorary Professor in the School of History and Philosophy of Science at the University of Sydney, is an Australian scholar of outstanding achievement and international standing. Her work is particularly notable in that she has made significant contributions to answering key questions in the history of science, especially in the history and historiography of evolutionary theory, as well as to the study of contemporary research policy in science and medicine. Her studies in the contextual history of evolutionary biology are internationally regarded as offering a major advance in the understanding and interpretation of the scientific past. Her recent book on the genesis and reception of Charles Darwin's concept of sexual selection, *Darwin and the Making of Sexual Selection*, has generated substantial international impact, being awarded the 2018 Suzanne J. Levinson Prize of the U.S. History of Science Society. Equally remarkable during her career has been her engagement with the history and socio-politics of medicine and their policy implications, demonstrating the importance of historical and sociological analyses in illuminating medical practices and policy, particularly in relation to clinical trials and drug regulation.

5) Walter Burfitt Prize 2019 — Professor Kourosh Kalantar-Zadeh

The **Walter Burfitt Prize** is awarded every three years to a resident of Australia or New Zealand for research in the pure or applied sciences that is deemed to be of the highest scientific merit, judged according to scientific output published during the preceding six years.

Professor Kourosh Kalantar-Zadeh, of the School of Chemical Engineering at UNSW Sydney, is renowned for his research and development in the areas of liquid metals, atomically thin materials and ingestible sensors. He is a prolific researcher, recognised in 2018 by Clarivate Analytics as a "Highly Cited Researcher." Over the past six years, his contributions have been frequently first-in-world and have set the agenda for research fields internationally in areas such as two-dimensional (2D) materials, liquid metals and microfluidics, and point-of-care diagnostic systems and sensors.

6) Jak Kelly Award 2019 — Mrs Gayathri Bharathan

The winner of the **Jak Kelly Award** for 2019 is **Gayathri Bharathan** from Macquarie University. Her research pursues the development of mid-infrared fibre lasers for medical and spectroscopic applications.

The Jak Kelly Award encourages excellence in postgraduate research in physics. The winner was selected from a short list of candidates who made presentations at a recent joint meeting at UNSW of the Australian Institute of Physics NSW Branch, the Royal Australian Chemical Institute, and the Royal Society of NSW.

7) Royal Society of New South Wales Scholarships 2019

The **Royal Society Scholarships**, valued at $500, together with a complimentary year of associate membership of the Society, are awarded annually in order to acknowledge outstanding achievements by young researchers in any field of science. Applicants must be enrolled as research students in a university in either NSW or the ACT on 1 January in their year of nomination.

For 2019, the RSNSW Scholarships have been awarded to:

- Ms Emma Austin — The University of Newcastle
- Mr Shayam Balaji — The University of Sydney
- Mr Michael Papanicolaou — University of Technology Sydney and the Garvan Institute of Medical Research
- Mr Thomas Pettit — University of Technology Sydney

Note on Gazetting

The Government Gazette of the State of New South Wales is managed by the New South Wales Parliamentary Counsel's Office and has published Government notices, regulations, forms and orders since 1832. It went on line in 2001 and since 2014 is only to be found at https://www.legislation.nsw.gov.au/#/gazettes.

On the initiative of RSNSW Fellow Robert Whittaker AM FRSN, the Society approached His Excellency the Governor to formally gazette fellows of the Society. All current fellows were included in the first gazetting in 2018, and subsequently at the beginning of each year fellows elected in the previous year will appear in the Gazette.

As the Gazette of Thursday 31 January 2019 says:

> "His Excellency, General The Honourable David Hurley AC DSC (Ret'd), Governor of New South Wales, as Patron of The Royal Society of New South Wales and in furtherance of the aims of the Society in encouraging and rewarding the study and practice of Science, Art, Literature and Philosophy, is pleased to advise and acknowledge the election of the following as Fellows and Distinguished Fellows of the Society."

Fellows

Proven leaders and experts in their field, entitled to use the post nominal FRSN. Please note Professorial titles — including adjuncts, conjoint, and professors of practice — have been used where applicable. Details as to their field of expertise, their resident university (or universities) or institution may be ascertained from the Royal Society of New South Wales.

AMAL, Scientia Professor Rose Amal AC FRSN

AUSTIN-BROOS, Professor Emerita Diane Austin-Broos FRSN

BATHURST, The Honourable Chief Justice Thomas Bathurst AC FRSN QC

BELOV, Professor Katherine Belov FRSN

BHATHAL, Dr Ragbir Bhathal FRSN

BIRD, Professor Trevor Bird FRSN

BLACKBURN, Air Vice Marshal John Blackburn AO FRSN

BORODY, Professor Thomas Borody FRSN

BROADBENT, Chancellor Dr Jillian Broadbent AO FRSN

BUTLER, Rear Admiral (USA) John Butler CBE FRSN DSM(US)

CARMICHAEL, Professor David Carmichael FRSN

CARTER, Emeritus Professor John Carter AM FRSN

CHOUCAIR, Dr Mohammad Choucair FRSN

COMPTON, Professor Mark Compton AM FRSN

COVELL, Emeritus Professor Roger Covell AM FRSN

DAVIS, Emeritus Professor Jeremy Davis AM FRSN

DI PIETRO, Commodore Vincenzo Di Pietro AM CSC FRSN

DOOLEY, Professor Anthony Dooley FRSN

EDMOND, Professor Gary Edmond FRSN

FARNSWORTH, Dr Alan Farnsworth AM FRSN

HARRIS, Chancellor Mr James Harris FRSN

HARRISON, Conjoint Professor Alexander Harrison FRSN

HIBBERD, Professor Adrian Hibberd FRSN

HILTON, Dr John Hilton FRSN

HINTZE, Sir Michael Hintze AM FRSN

HUPPERT, Emeritus Professor Herbert Huppert FRS FRSN

HUSH, Dr David Hush FRSN

HUSH, Associate Professor Julia Hush FRSN

HUTCHINSON, Chancellor Ms Belinda Hutchinson AM FRSN

JEFFERY, Dr, Major General, The Honourable Philip Michael Jeffery AC AO(Mil) CVO MC FRSN

KARA, Professor Sami Kara FRSN

KARSKENS, Professor Grace Karskens FRSN

KINGSFORD, Professor Richard Kingsford FRSN

KIRBY, The Honourable Michael Kirby AC CMG FRSN

LOOSLEY, Mr Stephen Loosley AM FRSN

MacDONALD, Professor Heather MacDonald FRSN

MACKIE, Professor Vera Mackie FRSN

MASON, The Honourable, Sir Anthony Mason AC KBE FRSN QC

MIDDLETON, Emeritus Professor Jason Middleton FRSN

MORONEY, Commissioner (Rtd) Dr Kenneth Moroney AO FRSN

NEW, Associate Professor Elizabeth New FRSN

OZDOWSKI, Commissioner (Rtd) Dr Seweryn Ozdowski AM FRSN

PALMER, Mr George Palmer AM FRSN QC

POND, Dr Susan Pond AM FRSN

QUILTY, Dr Ben Quilty FRSN

RICHARDS, Honorary Professor Evelleen Richards FRSN

SAHAJWALLA, Scientia Professor Veena Sahajwalla FRSN

SENGELMAN, Major General Jeffrey Sengelman DSC AM CSC FRSN

SHARPE, Ms Wendy Sharpe FRSN

SILBERBERG, Dr Ronald Silberberg AO FRSN

SMITH, Professor Lee Smith FRSN

SPENCE, Vice Chancellor and President Dr Michael Spence AC FRSN

STODDART, Professor Sir James (Fraser) Stoddart FRS FRSN

STORRIER, Dr Timothy Storrier AM FRSN

SWAN, Professor Peter Swan AO FRSN

TABBAA, Commissioner (Rtd) Ms Inaam Tabbaa AM FRSN

THOMAS, Mr Robert Thomas AM FRSN

TISDELL, Professor Christopher Tisdell FRSN

TORERO, Dr Jose Torero FRSN

TROWELL, Dr Stephen Trowell FRSN

VANN, Vice Chancellor and President Andrew Vann FRSN

WATERHOUSE, Emeritus Professor Richard Waterhouse FRSN

WELLINGS, Vice Chancellor and President Professor Paul Wellings CBE FRSN

WILLIAMSON, Professor Geordie Williamson FRS FRSN

WILLIS, Professor George Willis FRSN

ZHAO, Professor Chuan Zhao FRSN

The following had been previously admitted as Fellow of the Society but were not appropriately attributed in the NSW Government Gazette:

FLAMBAUM, Scientia Professor Victor Flambaum FRSN

GRIFFIN, Dr Desmond Griffin AM FRSN

HILL, Emeritus Professor Stephen Hill AM FRSN

HERRMANN, Dr Jan Herrmann FRSN

IRISH, Associate Professor Muireann Irish FRSN

MOYAL, Dr Ann Moyal AM FRSN

ROBERTS, Scientia Professor John Roberts FRSN

TAYLOR, Professor Mark Taylor FRSN

Archibald Liversidge:
Imperial Science under the Southern Cross

Roy MacLeod

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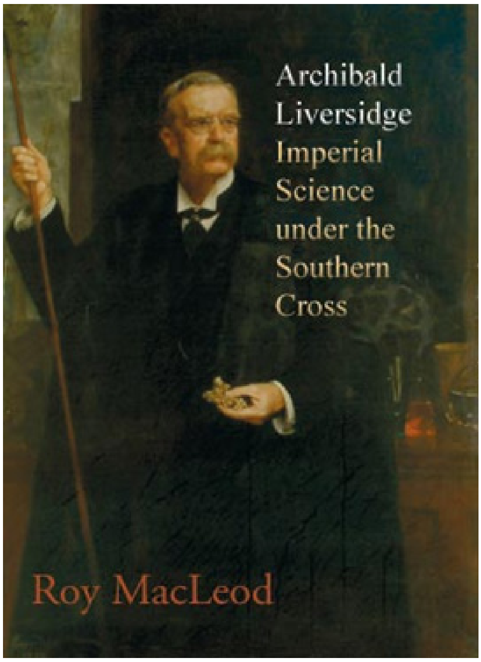

When Archibald Liversidge first arrived at the University of Sydney in 1872 as Reader in Geology and Assistant in the Laboratory, he had about ten students and two rooms in the main building. In 1874, he became Professor of Geology and Mineralogy and by 1879 he had persuaded the University Senate to open a Faculty of Science. He became its first Dean in 1882.

In 1880, he visited Europe as a trustee of the Australian Museum and his report helped to establish the Industrial, Technological and Sanitary Museum which formed the basis of the present Powerhouse Museum's collection. Liversidge also played a major role in establishing the A*ustralasian Association for the Advancement of Science* which held its first congress in 1888.

This book is essential reading for those interested in the development of science in colonial Australia, particularly the fields of crystallography, mineral chemistry, chemical geology and strategic minerals policy.

To order your copy, please complete the Liversidge Book Order Form available at:

http://royalsoc.org.au/publications/books/McLeod_Liversidge_Order_Form.pdf

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The Royal Society of New South Wales

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Papers (other than those specially invited by the Editorial Board) will only be considered if the content is either substantially new material that has not been published previously, or is a review of a major research programme. Papers presenting aspects of the historical record of research carried out within Australia are particularly encouraged. In the case of papers presenting new research, the author must certify that the material has not been submitted concurrently elsewhere nor is likely to be published elsewhere in substantially the same form. In the case of papers reviewing a major research programme, the author must certify that the material has not been published substantially in the same form elsewhere and that permission for the Society to publish has been granted by all copyright holders. Letters to the Editor, Discourses, Short Notes and Abstracts of Australian PhD theses may also be submitted for publication. Please contact the Editor if you would like to discuss a possible article for inclusion in the Journal.

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info@royalsoc.org.au (general)
editor@royalsoc.org.au (editorial)
www.royalsoc.au
www.facebook.com/royalsoc

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