MATHEMATICS AT THE MINT: A SEVENTEENTH-CENTURY SAGA

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Introduction

THE work of Christopher Challis[1] and Jack Williams[2] has shown how mathematics was central to the work of the mint master and assayer. An inevitable consequence was that tensions arose when the precise light of arithmetic confronted the bold but crude requirements of authority. Our story will centre on the lives of two men on opposite sides of this divide, John Reynolds and Thomas Aylesbury. Both of them were influential in the extended mathematical community that existed in England in the first half of the seventeenth century, although neither made any original contributions to mathematics. We shall unravel the technical issues that led to a bitter dispute between these two protagonists, and catch a few glimpses of the murky world of politics and government under the Stuart kings.

Mathematics and money

The value of a gold or silver coin depended on two factors: its weight and its fineness (the proportion of precious metal that it contained). The determination of the value thus required complicated calculations. In the high middle ages the introduction of the Hindu-Arabic numerals and the associated algorithms enabled the calculations to be done more easily but, as we shall see, the inherent complexity remained. The *Liber Abbaci*, written by Leonardo of Pisa (Fibonacci) at the beginning of the thirteenth century, began by describing the arithmetical algorithms for addition, subtraction, multiplication, and division, and significantly the book went on to explain how such methods could be applied to a wide range of commercial problems: in particular, 'the alloying of monies'. It may not be a coincidence that Fibonacci was summoned to the court of Frederick II of Sicily around 1225, at the time when Frederick was trying to re-establish a coinage of gold in Europe.

Several other great names in the history of mathematics appear in the annals of assaying and coinage. Robert Recorde (1512–58), the author of widely-used books on arithmetic, held various posts at the Mints in England and Ireland, and died as a result of his belief that his aristocratic masters were fiddling the accounts.[3] John Napier, the inventor of logarithms, was the son of Archibald Napier, the General of the Scottish Mint, and brother of Francis Napier who was appointed assayer in 1581. In 1604 copies of the weights used at the Tower Mint in London were sent to Edinburgh for comparison, and it is likely that John himself assisted in this work.[4] And of course Isaac Newton was Warden of the Tower Mint from 1696 to 1699 and Master from 1699 until his death in 1727. During that time he made numerous calculations involving the weight and fineness of English and foreign coins.[5] His insistence that the values assigned to the current coins should be correct arithmetically was part of a process that led ultimately to the introduction of the Gold Standard in England, although that did not happen until much later.

[1] The general background to events at the Tower Mint is discussed in Challis 1992a. Some details of John Reynolds and his dispute with Thomas Aylesbury are given in Challis's Presidential Address to the BNS (Challis 1992b), and his list of Mint personnel (Challis 1989) is also very useful.

[2] Williams 1995, 2011.

[3] Williams 2011.

[4] Napier's expertise in metrology is mentioned by Connor and Simpson 2005, 340.

[5] Shaw 1896, 133–79.

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John Reynolds

John Reynolds' early career can be traced in the records of the Goldsmiths Company.[6] He was apprenticed as a goldsmith in 1599, and made free in 1606. He may well have been a mathematical prodigy: certainly there are good reasons for thinking that his mathematical abilities played a major part in his early advancement. His master was Richard Rogers the younger, Comptroller of the Mint from 1599 to 1636. Rogers had himself been trained by his uncle, Richard Rogers the elder, a goldsmith and assayer who had a long association with the Mint. Reynolds also received training in arithmetic from John Goodwyn, one of the foremost teachers of the time. The impression that he was being prepared for a career as the resident mathematician at the Mint is reinforced by the fact that in 1607, soon after being made free, he was appointed as an assistant to the Assay-Master.[7] The next that we hear of him is quite remarkable. Sir Richard Martin, the current Master of the Mint, had been working there since 1572, and many people, both inside and outside, wished for a new broom. Martin's son, also called Richard, had been appointed joint Master in 1599, and doubtless he had expectations of eventually taking charge. Nevertheless, the records show that John Reynolds was granted a reversion on the post of Master in 1609, only two years after being appointed as an assistant. The background to this event, and its implications, will probably never be known, but it is an established fact. Reynolds was then in his mid-twenties, without experience of high-level appointments, and the position to which he might be expected to succeed was an important one, requiring personal qualities as well as mathematical prowess.

In the event Reynolds' expectations were not fulfilled: when Martin eventually died in 1617, the post went to a quite different kind of man. He was Sir Edward Villiers, the half-brother of the king's favourite, George Villiers, Duke of Buckingham. Clearly, we need look no further for the reason for his preferment. The Mint had a vital part to play in the national economy, and the Master could make serious money for himself as well as providing for the nation's currency. It is recorded that Villiers took many opportunities for personal gain in his years at the Mint, and this cannot have endeared him to those who worked under him. A great deal of expertise in technical matters was needed to keep the Mint running smoothly, and that was provided by people like Richard Rogers and John Reynolds, without whom the Mint's operations would have been impossible.

The situation at the Mint may have prompted Reynolds to look for other opportunities, and when the post of assayer to the Goldsmiths Company fell vacant in 1619, he was appointed. The Goldsmiths Company was a powerful organization, not simply a guild of craftsmen, and its Wardens were wealthy men with connections in many areas of business, finance, and government. The Company's significance in national terms stemmed from its responsibility for ensuring that all items of silverware were of the correct standard. The assaying done at Goldsmiths Hall was thus of great importance, and this was now to be controlled by Reynolds. Although his tenure began well, by 1625 there were clear signs of difficulty between him and his employers. Partly this was due to the fact that he was not in full-time attendance at the Hall, being occupied with duties at the Mint and possibly elsewhere. But there was also a technical problem, which went right to the heart of the practice of assaying, and Reynolds fell out with the Wardens as a result. The matter rumbled on for several years, with many twists and turns, until he finally left the Goldsmiths on 18 June 1630. As we shall see, he was soon to become embroiled in another dispute of a similar kind, where the requirements of authority were at odds with the technical realities.

[6] See Challis 1992b for references to the Goldsmiths' archives. John Reynolds' family background will be discussed later in this article.

[7] *Calendar of State Papers Domestic*, *James I 1603–1610*, 373 (3 Oct. 1607). On p. 452 (13 Aug. 1608) there is mention of Reynolds in connection with an assay of silver.

The trouble with coins

In the sixteenth century Henry VIII had experimented with debasement of the currency, and Elizabeth had successfully restored its integrity. But the result was a bewildering array of coins, particularly in gold, where there were two standards of fineness: 'angel gold' at about 99.5 per cent pure, and 'crown gold' at about 91.7 per cent pure. The accession of James created more problems, since he wished to integrate some of his Scottish coins into the English system. A proclamation issued in 1604 set out the details with admirable clarity, specifying very precisely the correct weights of the coins in Hindu-Arabic numerals.[8] Another problem was the growing recognition that monetary factors, such as the relative values of the gold and silver coins, played an important part in the national economy. Consequently there was much theorizing about the management of the coinage, and frequent, rather clumsy, attempts to put the theories into practice.[9]

The first major change came in 1611, when the values of the gold coins were raised by one-tenth. A gold 'unite', previously worth 20 shillings, was now worth 22 shillings, and there were some very awkward denominations, such as a 'thistle crown' at 4*s*. 4½*d*. The 1611 proclamation did not match its 1604 predecessor in clarity, since it specified only the official values of the various coins (in Roman numerals), not their weights.[10] Its obscurity was compounded by an attempt to revive an old idea about allowing for the fact that coins became worn in use. The intention was that light coins should circulate at their full face value, provided they were not too light. Fixing a small allowance meant that there was a *least current weight* for each coin. The practical implications of this idea had never been properly worked out, and the wording of the proclamation was unhelpful. It was stated that anyone might lawfully refuse to accept a coin that fell below its least current weight, but it did not say what that weight was, and it did not say explicitly that coins above the least current weight should be accepted at their face value.

In 1619 a new proclamation heralded an attempt to overcome the inconvenience of the awkward denominations.[11] New gold coins with convenient values would be issued, such as a 20 shilling piece, to be known as a 'laurel'. The old coins continued to circulate with their awkward values, so that there were more than ten denominations of gold coins in circulation, including a few older coins from the time of Elizabeth. Some of these coins were not in pristine condition, and consequently the 1619 proclamation repeated the rules about least current weight; for example, a laurel could be refused if it was more than two grains lighter than its proper weight. The figures were now given in Hindu-Arabic numerals but, as in 1611, the proper weight was not stated in the proclamation, and could only be deduced from the instructions given to the Mint. These were expressed in the traditional format, requiring that 41 laurels should be struck from each pound of gold. Since the pound contained 5,760 grains, people proficient in arithmetic would have been able to deduce that the proper *mint weight* of a laurel should be 140 20/41 grains, and the least current weight 138 20/41 grains. In practice, people have always been averse to calculation, especially when fractions are involved. For this reason, special weights were used to assess the value of gold coins used in trade, a practice that goes back (in England) to the introduction of gold coins by Edward III in the middle of the fourteenth century.[12] In James's time the weights were square pieces of brass, usually stamped with an image resembling the obverse of the intended coin, and the value (Figure 1).

Given the variety of coins in circulation, a merchant would need a set of about ten weights of this kind, as well as small 'grain weights' to assess the deficiency of light coins. A good number of these weights have survived, and the *Corpus of British Coin-Weights* reveals significant variations in their actual mass.[13] Some of the laurel weights were close to the mint weight of 140 20/41 grains, but in everyday trade the key question was not whether a laurel was of full weight, but

[8] Larkin and Hughes 1973, 99–103, no. 47.
[9] Supple 1959.
[10] Larkin and Hughes 1973, 272–6, no. 122.
[11] Larkin and Hughes 1973, 436–9, no. 189.
[12] Biggs 2011.
[13] Withers and Withers 1993.

Fig. 1. Brass weight for checking a laurel of 20*s.* after 1619 (twice actual size; private collection)

whether it was worth the full 20 shillings. For this purpose a coin-weight corresponding to the least current weight of 138 20/41 grains was needed, and there are indeed a number of weights at this level.

In 1625, when James was succeeded by his son Charles, changes in the gold coinage were proposed. New coins with the effigy of the new king were surely needed, but some people saw this as an opportunity to alter the coinage in other ways. Among them was the aforementioned Duke of Buckingham, who remained the most powerful member of the Council. He was notoriously ignorant of foreign affairs, and seemed to believe that reducing the gold content of English coins would not affect their value in the international markets. Thus there emerged a proposal that 44 twenty-shilling pieces, instead of 41, should be minted from each pound of gold, with most of the resulting 'profit' going to the king. This stupid plan was actually implemented for a few weeks, but it was swiftly withdrawn, despite the efforts of Buckingham, and the coins reverted to their old rates.[14] The problem of maintaining a sound currency remained, and a proclamation issued in May 1627 set out new, even more obscure, rules for the gold coins.[15] Apparently the intention was that, for the 'odde' pieces minted before 1619, three categories were to be distinguished. In the case of the old unite, with current value 22*s*., the situation was as follows:

1. A coin lacking not more than 3 grains should be current at its full value.
2. A coin lacking more than 3 grains but not more than 6 grains should be current, but at a lesser value.
3. A coin lacking more than 6 grains should not be current, but should be taken to the King's Exchange, where it would be redeemed for its value as bullion.

The proclamation was worded in the usual legal jargon, and consequently it contained no specific weights or valuations. Thus the commercial world was ready for a little book published later that year, entitled *An Advice Touching the Currancie in payment of our English Golde. As also, A Table of the Severall Worths of all Pieces, uncurrant through want of weight, at his Ma*^{ties} *Exchanges in London.* There is no name on the title page, but there is no doubt that the author was John Reynolds.[16] His book contained useful information on the mint weight of the coins, and tables of their values according to the proclamation of 1627. But it could not resolve the underlying problems, the baroque complexity of the gold coinage and the rules for the valuation of individual coins.

[14] Shaw 1896, 3–20. The proclamation aborting the plan is Larkin 1983, 106–7, no. 52.

[15] Larkin 1983, 144–53, no. 69.

[16] There were several versions of Reynolds' *Advice*. One copy (British Library 1139 c.22) explicitly rejects a competing booklet, *The Free Exchanger*, as being 'full of errors'.

Thomas Aylesbury

The problems were particularly acute for the mercantile classes in London.[17] They complained that there was 'great deceit' in the many gold-weights produced in London and in Holland, even though they all bore the image of the king's head. Some of the variation was surely due to poor workmanship, but it was also pointed out that some weights were specifically intended to check the full 'mint weight' of the coin, while others were intended to check the 'least current weight'. After discussion in the Lord Mayor's Court, the matter was referred to the King's Council in April 1631, and it was decided that the solution was to ensure that all gold-weights were produced by a single, reliable, maker. It would have been possible to use the Mint for this purpose but, despite the claims of the Warden, that plan was rejected. On 17 May 1631 the King instructed the Attorney General to offer the position of maker of 'weights and balances for the King's moneys of gold' to Sir Thomas Aylesbury, for life. Aylesbury had not previously figured in the annals of coinage or weight-making, but that was clearly not an important consideration, in the King's opinion.

Thomas Aylesbury was born in 1576, and attended Westminster School and Christ Church Oxford before being appointed secretary to the Lord High Admiral, the Earl of Nottingham. He remained in this post in 1618 when Nottingham was ousted by none other than George Villiers, Duke of Buckingham. Although Buckingham's rule continued after the accession of Charles, he was very unpopular, and he was assassinated in 1628. By then Aylesbury had become a figure in his own right, as Surveyor of the Navy and one of the Masters of Requests. His connection with the Villiers family cannot have gone down well with the people who worked at the Mint, given the earlier activities of Edward Villiers as Master, and George's advocacy of the scheme for debasing the gold coins.

One possible reason for Aylesbury's appointment was that he had acquired a reputation as someone with contacts in the world of mathematics. He was not a mathematician, nor was he a practitioner of mathematics, but he had become involved with the group of scholars that the Earl of Northumberland had gathered together on his grand estate, Syon House, about 15 km west of London. The most gifted of them was Thomas Harriot, who had formerly been employed by Sir Walter Raleigh. In the comfortable surroundings of the Syon House estate Harriot was able to produce an enormous quantity of original work in many branches of science and mathematics, but none of this work was published. When he died in 1621, he left instructions that his papers should be sorted and perused with a view to some form of publication. This was not an easy task, partly because of the sheer volume of his work (over 8,000 pages), but mainly because much of it was far ahead of its time.[18] In his will Harriot appointed his friend Nathaniel Torporley as his literary executor, to be assisted if needed by four other gentlemen. Torporley failed to make progress towards publication, and in due course the task was taken on by Walter Warner, one of the four so named. He was assisted by another one of the four, none other than Thomas Aylesbury, who was also an executor of the will.

In many ways Aylesbury's background makes him an unlikely member of the Syon House group. He owed his advancement to the royalist clan, which was deeply distrustful of Harriot, mainly because of his association with Raleigh. When Raleigh was found guilty of high treason in 1603, Harriot had been cited as an evil influence on him. The death sentence on Raleigh was suspended at that time, but the gunpowder plot of 1605 led to Harriot's imprisonment on a trumped-up charge of using magical powers against the king. We know that Aylesbury corresponded directly with Harriot in 1613 and 1618,[19] which suggests that he had a genuine interest in mathematics, possibly strengthened by the knowledge that a reputation for competence in these areas might be useful in his career. But the clandestine nature of the Stuart regime forces us to consider the possibility that he had been instructed by his royal masters to keep an eye on the activities of the Syon House group. It is unlikely that Aylesbury was able to contribute

[17] TNA: SP 16/188 nos 21, 21/1, 21/2; 196 nos 81, 81/1.

[18] Harriot's papers are now available online at <http://echo.mpiwg-berlin.mpg.de/scientific_revolution/harriot> (accessed 11 Apr. 2016).

[19] Shirley 1983, 415.

much to the task of sorting the Harriot papers, but his support for Warner led to the publication of a volume entitled *Artis Analyticae Praxis* in 1631. Aylesbury remained on good terms with Warner, and after the death of the Earl of Northumberland in 1632 he continued to support him financially. This ensured that his contacts with the mathematical community were maintained. Unfortunately, his appointment as the 'sole maker' of coin-weights was to lead to trouble, some of it mathematical.

The dispute

Although the Mint had not been entrusted with producing the new weights, Aylesbury had the good sense to enlist three of its employees to assist him. They were Thomas Burgh (or Birch, clerk to the master), Nicholas Briot (an engraver), and John Reynolds. The number of weights required was large, and there was a great deal of preparatory work. Brass of the right quality was essential, and the dies had to be designed and cut. One important decision was made quite early in the process: the new weights should be round (Figure 2), in order that they could be easily distinguished from the old square ones.

Fig. 2. Brass weight for checking the unite of James I, issued in the reign of Charles I when the unite was valued at 22*s*. (twice actual size; private collection)

The project also provided Reynolds with the opportunity to produce an updated version of his *Advice Touching the Currancie*. It was entitled *Perfet* [sic] *Directions for all English Gold*,[20] and it contained pictures of the new coin-weights, as well as tables giving the values of the various coins according to their actual weight (Figure 3).

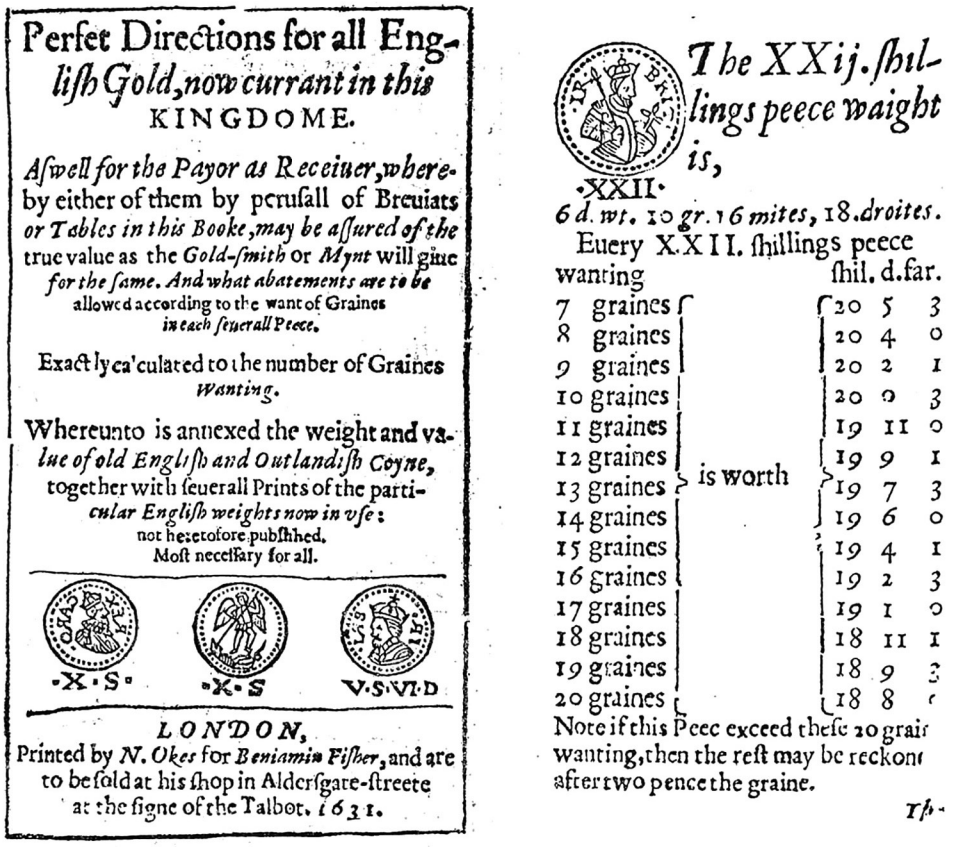
There is an edition of this book bearing the date 1631, which suggests that it appeared before the weights themselves were ready. Aylesbury's patent was not granted until 20 October 1632, and the weights were announced in a royal proclamation of 20 December 1632.[21]

In the *Perfet Directions* the table for each coin is headed by a drawing of the relevant coin-weight, and a statement of its weight. This is given with a higher level of precision than in the *Advice*, in terms of the following sub-units:

1 pennyweight = 24 grains, 1 grain = 20 mites, 1 mite = 24 droits.

For example, the weight for the 20-shilling piece is stated as 5 pennyweights 20 grains 9 mites 18 droits, which works out at 140 39/80 grains, whereas in the *Advice* it had been given as 5 pennyweights 20 grains 10 mites, which is 140½ grains exactly. In fact the mint indenture actually called for 20-shilling pieces to be minted at the average weight of 140 20/41 grains. The difference between the mint figure and the *Perfet* approximation is 20/41 – 39/80 = 1/3280 of a grain, which is about 0.02 mg, and could not have been detected by any balance available at that time. (In 1679 it was alleged that the best scales then available in London were sensitive

[20] Reynolds 1631.
[21] Larkin 1983, 366–9, no. 164.



Perfet Directions for all Eng-
liſh Gold, now currant in this
KINGDOME.

Aſwell for the Payor as Receiuer, where-
by either of them by peruſall of Breuiats
or Tables in this Booke, may be aſſured of the
true value as the *Gold-ſmith* or *Mynt* will giue
for the ſame. And what abatements are to be
allowed according to the want of Graines
in each ſeuerall Peece.

Exactly ca'culated to the number of Graines
Wanting.

Whereunto is annexed the weight and va-
lue of old Engliſh and Outlandiſh Coyne,
together with ſeuerall Prints of the parti-
cular Engliſh weights now in vſe:
not heretofore publiſhed.
Moſt neceſſary for all.

·X·S· ·X·S V·S·VI·D

LONDON,
Printed by *N. Okes* for *Beniamin Fiſher*, and are
to be ſold at his ſhop in Alderſgate-ſtreete
at the ſigne of the Talbot. 1631.

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lings peece waight
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·XXII·

6 d. wt. 10 gr. 16 mites, 18. droites.

Euery XXII. ſhillings peece

wanting		ſhil.	d.	far.
7 graines	is worth	20	5	3
8 graines		20	4	0
9 graines		20	2	1
10 graines		20	0	3
11 graines		19	11	0
12 graines		19	9	1
13 graines		19	7	3
14 graines		19	6	0
15 graines		19	4	1
16 graines		19	2	3
17 graines		19	1	0
18 graines		18	11	1
19 graines		18	9	3
20 graines		18	8	0

Note if this Peec exceed theſe 20 grain
wanting, then the reſt may be reckon
after two pence the graine.

Th·

Fig. 3. The title and a typical page from the *Perfet Directions*

to 1/740th of a grain.[22]) The proclamation of 20 December 1632 called for the weights to be 'of the full and just size according to the true Weights of the Gold Moneyes, and Graines and halfe Graines shall be apart by themselves, to show the remedies and abatements as they ought to bee, and none of them shall be made with the remedies and abatements purposely taken off'. This statement, together with the evidence of the *Perfet Directions*, suggests that Reynolds set out to produce coin-weights that corresponded to the full mint weight of the relevant coin. It is hard to understand how a problem might have arisen, but arise it did, and with some force. The only thing that is clear is that Aylesbury was not satisfied with the coin-weights that were made. One possibility is that he wanted the weights made at the least current weight, rather than the mint weight, but that seems to contradict the terms of the proclamation. It may be that his dissatisfaction was a pretext for pursuing some personal grudge but, whatever the reason, it was serious enough for him to ask the Privy Council to have Reynolds confined in the Fleet prison. This happened in June 1633, by which time large numbers of weights had been produced and sold.

There are several official records relating to this affair, but they confuse, rather than illuminate, the nature of the underlying problems.[23] Reynolds petitioned the Privy Council for his release, claiming that he had lost a considerable sum of money, and his plea was eventually granted. But the Council decided that Aylesbury was in the right. It ordered that, 'one John Reynolds having falsely made weights under Sir Thomas Aylesbury', the proclamation of 1632

[22] Badcock 1679, towards the end of his explanation of Reynolds' tables. The number 740 is not arbitrary: it was used because the fineness of sterling silver is 37/40. It follows that calculations can lead to exact results if the mite (one-twentieth of a grain) is divided into 37 parts, so there are 740 parts to the grain. An assayer's balance should therefore be sensitive to one of these parts.

[23] Challis 1992b, 245, nn. 25–9.

should be renewed 'with such additions and amendments as the Attorney General, conferring with Aylesbury, may find requisite.' The renewed proclamation appeared in May 1634.[24] That must have settled the local difficulty in Aylesbury's favour, but events at a national level would eventually supervene.

The fall of the royalists

The triumph of Aylesbury over Reynolds was symptomatic of the state of national affairs in the 1630s, when the machinery of government and administration fell almost entirely into the hands of staunch royalists, and their authority reigned supreme. In 1635 Thomas Aylesbury was appointed as one of two commissioners for the position of Master-worker of the Mint, replacing Robert Harley, who had held the position since 1626, in theory.[25] We cannot be sure of Aylesbury's real views regarding the royalist cause, but it is beyond doubt that he owed his rise to men who were supporters of the king and, when that party began to lose power, his fall was inevitably linked with theirs. Parliament took control of the Tower Mint in 1642, and within a year Harley had been restored as Master. Aylesbury removed himself to the king's stronghold in Oxford, although he later claimed that this was the result of infirmity rather than conviction.[26] After the king was executed in 1649, he thought it wise to leave the country, living in Antwerp from 1649 to 1652 and in Breda (where the royal court-in-exile was based) until his death in 1657.

This somber phase of Aylesbury's life is the part that holds greatest interest for historians of mathematics, because there is a suspicion that he took with him some of the Harriot papers, or copies of them. In his will, Harriot had stipulated that his papers should be sent to Petworth House, the Sussex home of the Earl of Northumberland. But what actually happened is unclear, as is Aylesbury's role in the matter. In the Interregnum the government kept close watch on what went on in Breda, and regularly intercepted the coded messages that were sent to and from the exiled court. Their chief cryptographer was John Wallis, later to become Savilian Professor of Mathematics at Oxford, and he may well have been privy to all kinds of secret information. He was also a friend of John Pell, who had lived in Breda from 1646 until 1652. Pell met Aylesbury on many occasions, and discussed mathematics with him. If Aylesbury had indeed sent all Harriot's papers to Petworth House, it is therefore puzzling that Pell and Wallis were not aware of it. At this time the belief that the papers contained significant new material was commonplace in the mathematical community, and in 1662, soon after the formation of the Royal Society, extensive enquiries as to their whereabouts were made. There were several rumours, but no firm information was forthcoming.[27] It was not until 1784 that large numbers of Harriot's papers were found at Petworth House, as Harriot himself had willed. And it took over two centuries more before they were made available for study by the general public.[28]

John Reynolds restored

The imprisonment of Reynolds at the hands of Aylesbury in 1633 cannot have been conducive to an easy working relationship, especially during Aylesbury's reign at the Mint from 1635 to 1642. Nevertheless, it appears that Reynolds retained a position as a clerk in the Tower throughout that time.[29] In fact we have concrete evidence of his expertise in another area of mathematics, not mentioned thus far.

[24] Larkin 1983, 420–3, no. 183.

[25] In practice, Harley's position had been complicated by a long-running legal battle with his predecessor: Challis 1992a, 273–9.

[26] Challis 1992a, 281, quoting evidence given by Aylesbury to the Committee on Compounding, whose function was to extract reparations from royalist supporters. It is ironic that the Committee was based in Goldsmiths Hall.

[27] Shirley 1983, 8–9.

[28] See n. 18.

[29] Challis 1989, 172.

In the sixteenth century, after much difficulty, some semblance of order in the national standards of measurement had been established, but the job was unfinished. In particular the measurement of capacity was a complete mess: a gallon of wine was not the same as a gallon of ale, and a gallon of grain was different again. The problem was compounded by the difficulty of constructing accurately the standard vessels that were needed to define the various gallons. John Reynolds' expertise in arithmetic and precise measurement was clearly much needed. So it is not surprising to find a cylindrical jug,[30] inscribed with the royal arms, the date 1641, and the words WINE POTTLE TRYED BY JOHN RENALDS AT THE TOWER. A pottle was half a gallon, or four pints. A similar pint measure has been recorded but its current location is unknown.[31]

The background to Reynolds' work on capacity measures was described in 1650 by John Wybard in his treatise *Tactometria*.[32] Wybard says that it was 'above 50 years' since John Goodwyn, Reynolds' master in mathematics, had published a book of tables in which the ratio between the wine gallon and the ale gallon had been stated to be 4:5. Goodwyn's book has not survived, but in 1633 he wrote an encomium for Nicholas Hunt's *Handmaid to Arithmetick*, and in that book the ratio is said to be 3:4.[33] Reynolds told Wybard and his friend Edmund Wingate that there were standard measures kept in the Tower, and these were 'the most ancient and true'. He assisted Wybard in testing the measures kept at the Guildhall, which, as he expected, did not agree with the Tower standards.

King Charles was executed on 30 January 1649. In the Mint accounts for 1648–49 Reynolds appears only as one of the clerks, but in a list of Mint personnel approved by the Council of State in June 1649 he is restored to his old title of under assay-master.[34] This was the signal for a renewed burst of activity in his traditional areas of expertise. In 1651 there appeared his *Brief and Easie way by Tables to cast up Silver to the standard of XI Ounces ij Peny-weight. And Gold To the Standard of XXII Carracts, with Questions wrought by the Golden-Rule: also by Decimal Tables*.[35] This book contains extensive tables intended to simplify the calculations involved in the assay-master's daily problems. For example, if a certain weight of silver is available, and it has been assayed as being so much worse than the sterling standard, how much pure silver must be added to make an alloy of the standard fineness? The user of the book was expected to be proficient in the simple algorithm for adding quantities of silver expressed in units down to a mite, but the harder part of the calculation, involving multiplication and division, was done by the tables. In the same year Reynolds helped to produce tables of the weight and fineness of numerous foreign coins, accompanied by an explanation of the importance of these figures in the business of international trade.[36]

Reynolds continued to work well into his seventies. In 1654 he was paid for the work involved in making a large quantity of foreign silver ready for coining,[37] and in 1658 he was one of those who represented the Mint at Oliver Cromwell's funeral, with his traditional title of under assay-master. There are records of measures verified by him in 1659: an ale-gallon, and a new departure, a standard yard.[38] And, also in 1659, he reported on the assay of a consignment of copper from Nova Scotia.[39]

[30] Connor and Simpson 2005, 235.
[31] Connor and Simpson 2005, 259, n.89.
[32] Wybard 1650, Part III, Section II.
[33] Hunt 1633, 279.
[34] The accounts for 1648–49 are printed in the appendix to Fleetwood 1745. The changes in June 1649 are discussed by Challis 1992a, 325.
[35] Reynolds 1651; Bryant 1960, 114.
[36] Shaw 1896, 85–90.
[37] *Calendar of State Papers Domestic: Interregnum 1654*, 505.
[38] Connor 1987, 243, 272.
[39] *Calendar of State Papers Colonial, America and West Indies, Volume 1: 1574–1660*, 478.

The man and his legacy

There is clear evidence that John Reynolds was acquainted with such prominent mathematical practitioners as John Goodwyn, John Wybard, and Edmund Wingate. But in genealogical terms he is an elusive character. The name Reynolds is quite a common one, and it was written in many different ways: Rainolds, Reginald, Reginolles, and so on. Genealogists and historians alike have been confused by the many and varied occurrences of the name. For example, there were at least four people with the name John Reynolds who wrote books in the first half of the seventeenth century, a fact which led to our John being mistakenly credited with some very strange publications.[40] Eva Taylor conjectured that our John was the son of another John Reynolds (fl. 1582–1636), an instrument maker who was (possibly) identical with yet another John Reynolds, a master gunner.[41] But Christopher Challis found that in the apprenticeship records of the Goldsmiths Company the father of our John is named as William Reynolds. This William is stated to be a fletcher although, as Challis points out, that is not necessarily an indication of his real profession. In fact there is a will in the National Archives, dated 1618, of a William Reynolds of the precinct of Bridewell, London, who describes himself as a citizen and goldsmith.[42] The will reveals that this William had been born in Dartford, Kent, and had become a wealthy man. He was twice married, which may account for his wealth, as well as his extended family. He owned the Manor of Thriplow Bury in Cambridgeshire, which he left to his eldest son Nicholas, and he made large monetary bequests to many other members of his family. However he was probably not the father of our John: although his will names many relatives, only one was called John, and that was his 'very loving cozon and friend John Reynolds of Greenwich', who received forty shillings to buy him a ring.

The few references that we have to our John's familial relationships are tantalizingly obscure. His plea for release from the Fleet was sent to Sir Francis Windebank, Secretary of State, by a certain 'John Skidmore', who refers to Reynolds as an honest true dealing man and brother to 'our landlady'.[43] This Skidmore is almost certainly Sir John Skidmore (Scudamore) of Holme Lacy in Herefordshire; but the circumstances are mysterious. Skidmore was a staunch royalist, and (like Windebank) he was suspected of Roman leanings: his note to Windebank about Reynolds also refers to work on some documents for 'the Italian', which cannot be entrusted to others. He had a London house in Petty France, but whether it was owned by Mary, the sister of John Reynolds, is unknown. The mystery of Skidmore's support for Reynolds is compounded by another link with the world of mathematics. The renowned mathematician Thomas Allen had resided with the Skidmore family at Holme Lacy,[44] and it is said that he had also taught Sir Thomas Aylesbury. But apparently Skidmore and Aylesbury had very different views about John Reynolds.

Another possible allusion to the family of John Reynolds occurs in a letter from Michael Dary to John Collins, written in 1663.[45] Dary was a marginal figure in the mathematical community, whereas Collins was at the centre, and was known to his contemporaries as 'our Mersenne'. In this letter Dary asks Collins to present his respectful duty to 'grandsire Reynolds' and 'my father Bond'. The second worthy was Henry Bond, famed for his (unsuccessful) attempts to calculate longitude by the dip of the compass needle, who was in fact Dary's father-in-law. The first was almost surely our John Reynolds, but the significance of the term grandsire is not clear: it may have been simply a courtesy title for a man who was then nearing the age of 80. Whatever the implication, the letter implies that Reynolds was one of Collins' many acquaintances in the new world of mathematics that accompanied the restoration of the monarchy.

[40] Bryant 1960.
[41] Taylor 1954, 186, 194.
[42] TNA: PROB 11/133/184.
[43] *Calendar of State Papers Domestic*: *Charles I 1633–4,* 359–61.
[44] Clarke 1898.
[45] Rigaud 1841, 99–101.

By the time the great plague reached London in 1665 Reynolds' life was drawing to a close. Sir Robert Moray, a close friend of Charles II, wrote about Mint affairs to the then Master, Sir Henry Slingsby, who had decamped to Yorkshire. He reported that Reynolds' death was imminent, and that he (Moray) had obtained an assurance from the king himself that the post of under assay-master should not be filled until Slingsby returned to London.[46] Perhaps that was a sign that an almost unknown man, with a modest title, had played an important part in the nation's affairs.

Tangible signs of Reynolds' legacy are easily found. His work on capacity measures was followed in 1670 by the distribution of standard bushel-measures throughout the nation, and in 1706, after much controversy, his standard wine-gallon of 231 cubic inches was adopted. His 'brief and easie' tables were reprinted by William Badcock in 1679,[47] and (with some improvements) by Thomas Snelling in 1766.[48] Newton's great labours on the valuation of foreign coins[49] followed the lines laid down by Reynolds in his report of 1651. And when, at long last, the government decided in the 1770s to reform its coinage of gold, they ensured that there were clear and sound rules as to the meaning of 'least current weight'.[50]

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[46] Challis 1991 176.
[47] Badcock 1679.
[48] Snelling 1766.
[49] Shaw 1896.
[50] Biggs 2004.