The cipher of Emperor Rudolf II's "Alchemical Hand Bell"

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Abstract

We examine a cipher found inscribed in the so-called "Alchemical Hand Bell" from the Kunstkammer of Emperor Rudolf II. We provide insight into the bell's history, a correction for an existing published transcription, perform statistical analysis of the ciphertext, and look at possible encryption methods and plaintext languages. Given the analysis, we examine the possibilities of digraphic and polyphonic ciphers and give a brief overview of how these were used in the historical context.

1 Introduction and Description

Figure 1: Hans de Bull, "Alchemical Hand Bell" of Emperor Rudolf II, ca. 1600, h. 7,8 cm; d. 6,3 cm, Vienna, Kunsthistorisches Museum, inv. no. Kunstkammer, 5969. https://www.khm.at/objektdb/detail/91976/. Source of images: Gannon (2019).

Figure 2: See figure 1.

Around 1600, the Prague goldsmith Hans de Bull cast two hand bells for Emperor Rudolf II (1552–1612). One of them has survived the past four centuries and is nowadays on display in the Kunsthistorisches Museum (KHM) in Vienna (figures 1 and 2).[1] This little *Kunstkammer* piece is fascinating in many ways. From a letter by the artist we know that it was cast from an alloy of the seven planetary metals – gold, silver, copper, iron, lead, tin and mercury – before it was gilt.[2] This was confirmed in a recently conducted XRF-analysis at the KHM.[3] Such a sevenfold alloy had been described by the Swiss physician and alchemist Paracelsus (1493/4–1541) who called it *Electrum* and provided astrological and alchemical instructions for creating efficacious artefacts out of it in his text corpus *Archidoxis magica* (Huser, 1590, Appendix, pp. 115–130).

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[1] Hans de Bull, "Alchemical Hand Bell" of Emperor Rudolf II, ca. 1600, h. 7,8 cm; d. 6,3 cm, Vienna, Kunsthistorisches Museum, inv. no. Kunstkammer, 5969. https://www.khm.at/objektdb/detail/91976/.

[2] Prague, archive Pražského hradu, Dvorská komora, box 5, no. 698 http://documenta.rudolphina.com/Regesten/A1612-10-00-02669.xml

[3] The results of this analysis will appear in Gannon (2024).

The sound of bells made from *Electrum* was supposed to summon planetary spirits and deities in order to provide their user insight into the secrets of the cosmos and therefore wisdom and power.[4] Emperor Rudolf II, who admired the Paracelsian philosophy and fostered the study of alchemy and natural magic at his court, must have been fascinated by such a promising material and likely appreciated a successful realization for his exquisite collection.

Whereas the "Alchemical Hand Bell's" intellectual and art historical background have been studied and reconstructed extensively (Bukovinská and Purš, 2010; Tilton, 2015; Gannon, 2019; Gannon, 2023b; Gannon, 2023a; Gannon, 2024)[5], a cryptological riddle remains to be solved. The decoration of the bell's mantle allows for a straightforward interpretation – the seven full-figure planetary deities, the corresponding signs of the zodiac, the symbols of the seven planets and metals, as well as a number of pseudo-Chaldean and pseudo-Arabic letters, visualize the interdependence between macro- and microcosm. A mystery is the spiraling Greek inscription that was carved into the inside of the bell's mantle. Each of the 163 letters can be identified; however, the inscription seems to contain no meaning. The iron clapper was also engraved with a spiraling Hebrew script, yet, the Hebrew letters are hardly legible and cannot fully be transcribed. Even though magical artifacts are often inscribed with nonsense script, for example another talisman created for Emperor Rudolf II whose reverse is adorned with similarly meaningless Hebrew letters (Gannon, 2020) – preferably corrupted Greek or Hebrew – it is tempting to suggest that at least the Greek sequence of letters may contain an encrypted message. It was not uncommon to hide alchemical recipes under a cipher (Piorko et al., 2023).

Also, since the bell was supposed to be used for summoning supernatural beings by calling their names, it is not unlikely that the inscription contains a list of such names. The English magus John Dee (1527–1608/09), for example, who sojourned in Prague with his 'scryer', the alchemist Edward Kelly (1555–1597), and tried to win the emperor's favor, practiced a comparable form of angelic magic. Similar artifacts and names to communicate with celestial beings were involved in his "angelic conversations" (Harkness, 1999; Clucas, 2006). In many cases, they appear to be a random stringing together of letters (Turner, 1986, p. 73). The question of whether this is also the case with the Greek inscription inside the "Alchemical Hand Bell" or whether it can indeed be deciphered as a legible plaintext remains to be answered. In the following, possible approaches will be presented.

2 Statistical analysis

The first published transcription of the ciphertext by Gannon (2019) contained a slight mistake which can be corrected as follows.

> ϑιδαγΗ ϑιβ κιδιγ ιιαϑδεγι ιαεϑιϑ δαιΗ κδειϑειζ Ηϑιγκδεγι δαΗι ιΗεϑδϑιζ ϑιδαγ Ηϑιβ κγκ βκειΗ ζειΗιει ζιδγΗειγ ϑιβ ιγαιβειγ ζιδιϑειΗ καιϑειζιΗ κιγδ δειΗ ιΗιδιγιΗ κιγδ δειΗ ΗεϑιαϑζειγζεϑιΗϑιΗ

Notably, each of the Greek letters in the ciphertext is from the first ten letters in the Greek alphabet. A transliteration of this into numerals would be:

> 783026 781 98382 88073428 804787 3086 93487485 678293428 3068 86473785 78302 6781 929 19486 5486848 58326482 781 82081482 58387486 908748586 9823 3486 86838286 9823 3486 6478075482 54786786

The frequency count is as follows (table 1).

From here on, we will use digits to represent each character, as contemporaneous ciphers with ten different characters often used the digits 0 through 9 and the letters are the initial letters of the Greek alphabet. We will also describe each block as a "word". Preserving the spacing, there are three repeated words: 781, 3486 and 9823. We see that in fact "9823 3486" is a two-word phrase repeated twice. Excluding spaces, we note two ten-number repetitions: 7830267819 and 8698233486. There are 53 unique bigrams (of a possible 100) with, for example, 86 and 48 occurring 12 times, and 78 occurring 11 times. The average word length is 6.04 with standard deviation

[4] On the ritual accompanying the use of the bell: Gannon (2019), Gannon (2024). On the connection between music and magical practices see Gannon (2023a).

[5] A detailed study of the "Alchemical Hand Bell" is part of Corinna Gannon's dissertation submitted in November 2022 at Goethe University, Frankfurt am Main and will be published in the future.

Greek Letter	Digit	Count
Α α	0	9
Β β	1	5
Γ γ	2	15
Δ δ	3	16
Ε ε	4	18
Ζ ζ	5	8
Η η	6	18
Θ ϑ	7	18
Ι ι	8	47
Κ κ	9	9

Table 1: Frequency count of ciphertext letters.

2.19. However, as the ciphertext is very short, this does not assist much with plaintext language identification, or for distinguishing between plaintext language candidates. In a cipher from around the same time period, Bean, Lang and Piorko (2022) noted that an observed average word length of 5.8 was too long for English but in line with Latin.

The calculated index of coincidence (IC) of the ciphertext is 3745/163/162 = 0.142. For the digraphic index of coincidence (DIC), it is 0.0269. Compared to Mason's table (Mason, 2005) we see that random digit ciphers, naturally, have an IC and DIC of 0.1 and 0.01. These values are quite distinct from those observed here. We note that 18 of the 27 words contain an even number of Greek letters. To check how common this is if the plaintext were ordinary Latin text, we performed sampling from 93 Project Gutenberg Latin books.[6] We generated one million examples of 27 word texts with the same proportions as from the books; about 1 in 12 samples had at least 18 of 27 words with even lengths.

We estimate the probabilities of the plaintext language as: Latin 60%, Greek 30% and German 10%. These estimates are based on the vernacular of Rudolf's court, the context of the cipher, and the contemporary context of objects of similar vintage. Another less likely option is Czech. Also, Hebrew inscriptions, as found on the clapper of the bell, are quite common, given Rudolf's interest in Kabbalah.[7]

3 Cipher type Diagnosis

These basic observations are a good starting point to try to diagnose the cipher type (Callimahos, 1977, Chapter XI). Two diagnosis tools, based on ACA ciphers and using machine learning techniques are currently available online: Mason (BION)[8] and the tool from Leierzopf et al. (2021) known as "NCID" [9]. Both tools provide a "probability" score in percentage terms ranking various possible ciphers. Using an input of digits, Mason's tool suggests the two most likely ciphers are Monome-Dinome (73) and Tridigital (23). With the ciphertext input as English letters, the top two outputs are Bazeries (25) and CheckerBoard (20). These are clearly anachronistic suggestions. The NCID tool has also been trained on ciphertext from the "key-phrase" cipher. Using English letter input, two reasonable suggestions are Checkerboard (48%) and key-phrase (5%). Other ciphers from the ACA list with similar index of coincidence statistics are shown in the following table; that is, selected rows from Mason's table. These four ciphers have output in the form of numbers and use a key square, a matrix, or a 5x5 Polybius square in the encipherment process. Note that these statistics are based on enciphered English plaintext using English keywords, which would have different statistical properties to Latin, Greek or German plaintext. The statistics are given as two values (table 2): the IC is multiplied by 1,000 while the DIC is multiplied by 10,000, and each value is given as a mean / standard deviation pair.

ACA Cipher Type	IC	DIC
Grandpré	128/3	179/15
Monome-dinome	124/7	249/36
Tridigital	122/8	195/29
Nihilist substitution	144/11	218/33

Table 2: Monographic and digraphic index of coincidence statistics for selected ACA ciphers. **IC** = Index of coincidence (mean/sd) times 1,000; **DIC** = Digraphic index of coincidence (mean/sd) times 10,000.

The Grandpré cipher was first introduced in 1905; the monome-dinome cipher is believed to date from the Spanish Civil War (c1936), while the Nihilist cipher dates from 19th century Russia. Thus, these ciphers in their current form cannot have been used for the hand bell. Other ACA ciphers with numerical output such as the "Pol-

[6] https://www.gutenberg.org/.
[7] See Gannon (2020).
[8] https://bionsgadgets.appspot.com/gadget_forms/refscore_extended.html.
[9] https://www.cryptool.org/en/cto/ncid.

lux" or "Morbit" cannot be in use as they are derived from Morse code which was developed in the 1840s. As noted, the table from Mason does not provide statistics for the "key phrase" cipher. The observed digraphic index of coincidence (0.0269) is quite high, as is the number of words with even length. Thus, a digraphic cipher cannot be excluded. However, the simplest interpretation would be that spaces indicate plaintext word divisions. Historically, the first digraphic cipher was described in della Porta (1563) which provided a 20 x 20 table mapping every combination of two letters to a unique symbol. A simpler process was not developed until the "Playfair" cipher of 1854 which mapped letter pairs using a 5 x 5 Polybius square.

4 Polyphonic ciphers

Given these statistics and observations, the cipher may well be a so-called "polyphonic cipher" where any single ciphertext letter can map to many plaintext letters. One example of a polyphonic cipher is the so-called "key-phrase" cipher described in Kahn (1996, 787), Gaines (1956, 103) and used as a common cipher in American Cryptogram Association challenges. The ACA website gives an example as follows, using the phrase "Give me liberty or give me death".[10]

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pt alphabet: abcdefghijklmnopqrstuvwxyz
CT alphabet: GIVEMELIBERTYORGIVEMEDEATH

pt: aciphertextlettermaystandfor
CT: GVBGIMVMMAMTMMMMVYGTEMGOEERV
pt: morethanoneplaintextletter.
CT: YRVMMIGOROMGTGBOMMAMTMMMMV.
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However, Kahn seems to indicate that this cipher was limited to one time period, around 1832, when it was used by the Duchess of Berry. Solution methods for longer polyphonic ciphers using simulated annealing are discussed briefly in Lasry, Megyesi, and Kopal (2021): They examine papal ciphers from the 16th century, which use digits. Various cipher examples from Meister (1906) are given by Tomokiyo (2019a; 2019b; 2020). Another simple and obvious basis for a ten-digit polyphonic cipher is with a ten-letter keyword, with all letters different. For example, with the keyword "artichokes":

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0 1 2 3 4 5 6 7 8 9
A R T I C H O K E S
B D F G J L M N P Q
U V W X Y Z
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[10] https://www.cryptogram.org/downloads/aca.info/ciphers/KeyPhrase.pdf.

5 Conclusion

Emperor Rudolf II was an avid collector of alchemical paraphernalia. The cipher from the hand bell is quite short and yet provides a considerable challenge in terms of diagnosis as there is little context, unlike the contemporaneous papal ciphers. In recent years, the research paradigm called the 'New Historiography of Alchemy' (Principe and Newman, 2001) has promoted the use of so-called 'RRR methods' to replicate historical recipes experimentally.[11] Discoveries such as that by Bean et al. (2022) demonstrate that, in the context of ciphers as well, alchemical secrets are not necessarily 'empty secrets' as had been claimed in the past (Eco, 2016). Yet the riddle of the hand bell cipher shows that we still lack understanding of some of the many different alchemical practices of secrecy (Lang, 2023). For instance, until successful cryptanalysis is achieved, it will be hard to tell if this is 'a real cipher' or some other form of symbolism which was meaningful to its creators, yet whose meaning we do not yet understand.

Further research on the cipher could include calculating the unicity distance of the ciphers discussed here in the suggested three plaintext languages. This would give some idea of whether a solution is even possible at this ciphertext length.

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[11] Reconstruction, replication, re-enactment; see Hendriksen (2020, 314). Corinna Gannon also applied this method and, in collaboration with Christoph Jäggy, tried to reconstruct the sevenfold alloy *Electrum* based on various recipes from Paracelsian sources. Results will be published in her PhD dissertation (submitted November 2022).

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