The cipher of Emperor Rudolf II's "Alchemical Handbell"

First Author
Affiliation / Address line 1
Affiliation / Address line 2
Affiliation / Address line 3
`email@domain`

Second Author
Affiliation / Address line 1
Affiliation / Address line 2
Affiliation / Address line 3
`email@domain`

Abstract

We examine a cipher found inscribed in the so-called "Alchemical Handbell" owned by Emperor Rudolf II. We provide 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 Handbell" of Emperor Rudolfs II, ca. 1600, h. 7,8 cm; d. 6,3 cm, Vienna, Kunsthistorisches Museum, inv. no. Kunstkammer, 5969.

In the Kunstkammer of the Kunsthistorisches Museum (KHM) in Vienna, Austria, a curious handbell is on permanent display (figures 1 and 2). It was created by Hans de Bull, ca. 1600,

Figure 2: See figure 1.

for Emperor Rudolf II, who was fascinated by alchemy and collected related manuscripts and objects (Gannon, 2019; Gannon, 2023a; Gannon, 2023b; Gannon, 2023c). He is said to have owned the famous "Voynich Manuscript" at around the same time (Zandbergen and Prinke, 2016). The bell is only 7.8 cm in height and 6.3 cm in diameter, but contains a 163 letter inscription in Greek text in the interior. The object number in the KHM collection is given as "KK 5969" and several pictures of the bell may be found on the museum website.[1] The bell was on display in the Metropolitan Museum of Art in New York City in 2019–2020, as a loan during the "Making Marvels" exhibition.[2] A replica is available from the KHM museum shop, made from gold-plated brass, with a silver-plated clapper.[3] The

[1] `https://www.khm.at/en/object/91976/`; `https://www.khm.at/de/object/91976/`.

[2] `https://www.metmuseum.org/art/collection/search/768774`; `https://www.metmuseum.org/exhibitions/listings/2019/making-marvels-science-splendor`.

[3] `https://www.imperialshop.at/en/p/replica-alchemist-bell-100000000019909`; `https://shop.khm.at/en/shop/detail/shop\%5BshowItem\%5D=100000000019909-1115-0`.

original was cast from an alloy of the seven "planetary metals" (gold, silver, copper, iron, mercury, lead and tin). The bell's surface was gilt; the clapper was made of iron. This alloy was described by the Swiss alchemist and physician Paracelsus who named it "Electrum" (Gannon, 2023c). The exterior shows figures of the seven planetary deities, their symbols and the corresponding signs of the zodiac. The inside of the bell shows a spiraling Greek inscription and the clapper a Hebrew inscription. Tilton (2015) referred to the bell as a "spirit-summoning bell". Gannon (2019) described the history of the bell and the rituals associated with the planetary spirits in further detail, and published an initial transcription. Here we present a corrected transcription of the Greek text, a statistical analysis of the observed letters, and some observations about known ciphers which are reminiscent of the observed ciphertext.

2 Statistical analysis

The first published transcription of the ciphertext unfortunately contained some errors. A corrected transcription is 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 Ηεϑιαϑζειγ ζεϑιΗϑιΗ

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 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.

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.

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.[4] 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 clap-

[4] https://www.gutenberg.org/.

per of the bell, are quite common, given Rudolf's interest in Kabbalah.[5]

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)[6] and the tool from Leierzopf et al. (2021) known as "NCID" [7]. 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.

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 handbell.

Other ACA ciphers with numerical output such as the "Pollux" 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.

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 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".[8]

```
pt alphabet: abcdefghijklmnopqrstuvwxyz
CT alphabet: GIVEMELIBERTYORGIVEMEDEATH

pt: aciphertextlettermaystandfor
CT: GVBGIMVMMAMTMMMMVYGTEMGOEERV
pt: morethanoneplaintextletter.
CT: YRVMMIGOROMGTGBOMMAMTMMMMV.
```

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

[5] https://www.khm.at/objektdb/detail/74259/?offset=77&lv=list, see Gannon (2020).

[6] https://bionsgadgets.appspot.com/gadget_forms/refscore_extended.html.

[7] https://www.cryptool.org/en/cto/ncid.

[8] https://www.cryptogram.org/downloads/aca.info/ciphers/KeyPhrase.pdf.

ciphers from the 16th century, which use digits. Various cipher examples from Meister (1906) are given by Tomokiyo (2019). 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”:

```
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
```

5 Conclusion

Emperor Rudolf II was an avid collector of alchemical paraphernalia, and was once said to have owned the famous Voynich manuscript (Zandbergen and Prinke, 2016). The manuscript is over 200 pages but has defied all attempts at language classification or interpretation. In contrast, the cipher from the handbell is much shorter and yet provides a considerable challenge in terms of diagnosis as there is little context, unlike the contemporaneous papal ciphers.

It is an interesting and open question as to whether it is more likely to find a solution to this than the Voynich MS. Further research 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.

Acknowledgments

References

Richard Bean, Sarah Lang, and Megan Piorko. 2022. Solving an alchemical cipher in a shared notebook of John and Arthur Dee. In *Proceedings of the 5th International Conference on Historical Cryptology HistoCrypt 2022*, number 188, pages 12–21. Linköping University Electronic Press.

Lambros Callimahos. 1977. *Military Cryptanalytics Part III.* NSA, Fort Meade.

Giambattista della Porta. 1563. *De Furtivis Literarum Notis vulgo. De ziferis Libri IIII.* Scotus, Naples.

Helen F Gaines. 1956. *Cryptanalysis: A Study of Ciphers and Their Solution*, volume 97. Courier Corporation.

Corinna Gannon. 2019. The alchemical hand bell of Rudolf II: A touchstone of art and alchemy. In Štěpán Vácha and Sylva Dobalová, editors, *Studia Rudolphina 19. Bulletin of the Research Center for Visual Arts and Culture in the Age of Rudolf II*, pages 81–97, Prag. Artefactum.

Corinna Gannon. 2020. The amulet of Rudolf II – Kabbalistic talisman and pansophic collectible. In Štěpán Vácha, editor, *Studia Rudolphina 20. Bulletin of the Research Center for Visual Arts and Culture in the Age of Rudolf II*, pages 83–101, Prag. Artefactum.

Corinna Gannon. 2023a. Der Klang von sieben Metallen. Die Alchemistische Tischglocke Kaiser Rudolfs II. In Philippe Cordez, Rebecca Müller, and Joanna Olchawa, editors, *Rhythms and Resonances: Sounding Objects in the Middle Ages*, Paris.

Corinna Gannon. 2023b. Die Alchemistische Tischglocke Kaiser Rudolfs II. – Kunstkammerstück und magisches Artefakt. *Wiener Jahrbuch.*

Corinna Gannon. 2023c. Electrum in the Kunstkammer of Rudolf II. objects made from seven metals. In Sarah Lang, Michael Fröstl, and Patrick Fiska, editors, *Alchemistische Labore. Praktiken, Texte und materielle Hinterlassenschaften / Alchemical Laboratories. Practices, texts, material relics*, pages 87–101, Graz. Grazer Universitätsverlag.

David Kahn. 1996. *The Codebreakers: The comprehensive history of secret communication from ancient times to the internet.* Simon and Schuster.

George Lasry, Beáta Megyesi, and Nils Kopal. 2021. Deciphering papal ciphers from the 16th to the 18th century. *Cryptologia*, 45(6):479–540.

Ernst Leierzopf, Nils Kopal, Bernhard Esslinger, Harald Lampesberger, and Eckehard Hermann. 2021. A massive machine-learning approach for classical cipher type detection using feature engineering. In *Proceedings of the 4th International Conference on Historical Cryptology HistoCrypt 2021*, number 183, pages 111–120. Linköping University Electronic Press.

William Mason. 2005. Reference statistics for ACA ciphers. *The Cryptogram*, May-June:4–6.

Aloys Meister. 1906. *Geheimschrift im Dienste der Päpstlichen Kurie von ihren Anfängen bis zum Ende des XVI. Jahrhunderts.* Ferdinand Schöningh, Paderborn.

Hereward Tilton. 2015. Bells and spells: Rosicrucianism and the invocation of planetary spirits in early modern Germany. 19/1:5–26.

Satoshi Tomokiyo. 2019. Identifying Italian ciphers from continuous-figure ciphertexts (1593). *Cryptologia*, 43(1):23–46.

René Zandbergen and Rafał T. Prinke. 2016. The Voynich MS in Rudolfine Prague. In Ivo Purš and Vladimír Karpenko, editors, *Alchemy and Rudolf II. Exploring the Secrets of Nature in Central Europe in the 16th and 17th centuries*, pages 279–314, Prag. Artefactum.