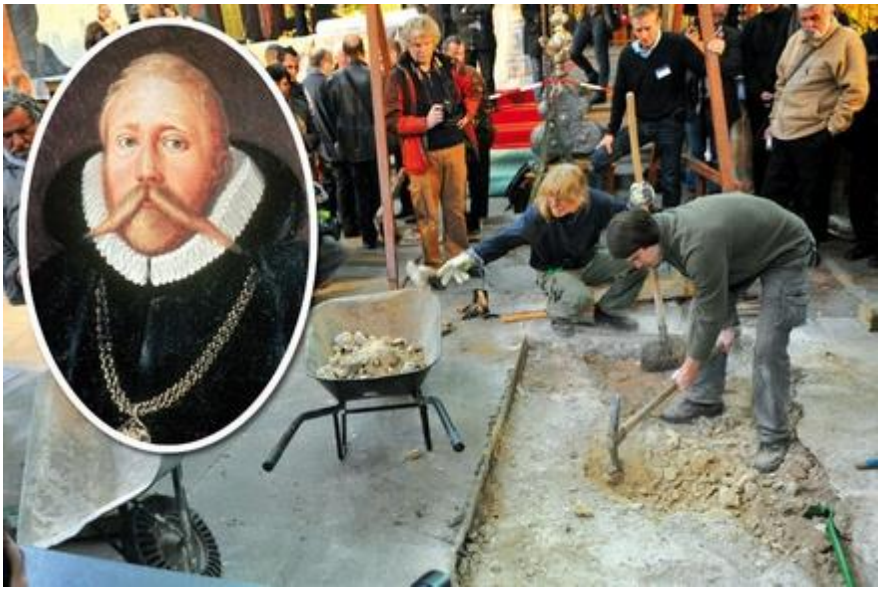
Investigating a Medieval Crime

On November 5, 2009, archaeologists exhumed the body of Tycho Brahe (1546 - 1601) from a tomb in Prague with the intention of clarifying the cause of the famous Danish astronomer's death. He is believed to have died from mercury poisoning. The researchers hope to use modern medical diagnostic tools to shed light on Brahe's medical history. They want to ascertain the real cause of death through the analysis of the remains of his bones, hair and clothing.



These tasks deal with mercury poisoning as well as with certain problems of mercury contamination through the mystery of Tycho's death.

Tycho Brahe was a well-known personality, a star-scientist in the Middle Ages - as we would say it today: a celebrity. He maintained contact with leading contemporary scientists, politicians as well as with many sovereigns (including the Hungarian king Rudolf).

At the age of fourteen he saw a partial solar eclipse in Copenhagen, which aroused his interest in astronomy: it was beyond question that he wanted to deal with this science - although his parents destined him for a legal career. Tycho Brahe's patron, King Frederick II of Denmark and Norway gave him financial support to build an observatory (and also offered to fund the construction of instruments and the cost of staff salaries) on the island of Hven, which became perhaps the most modern (and the era's most famous) observatory in Europe. On the island of Hven in 'Uraniborg' (or in the Gateway to the Heavens, as Brahe called it) there were farm buildings and residential buildings next to the observatory, as well as a printing press and a paper mill to provide material for publishing the fresh results locally.

Tycho received a distinctive injury during an episode of his eventful and adventurous life. While studying at the University of Rostock in Germany, on December 29 in 1566 he lost a part of his nose in a sword duel against a Danish nobleman, Manderup Parsbjerg. The duel itself was the result of a previous dispute:

Tycho had earlier quarrelled with Parsbjerg, at a wedding dance at Professor Lucas Bachmeister's house on the 10th, and again on the 27th. Two days later the duel in the dark resulted in Tycho losing the bridge of his nose. From this event Tycho became interested in medicine and alchemy. For the rest of his life, he was said to have worn a nose prosthesis made of silver and gold, using a special paste or glue to keep it attached. Some researchers, such as Fredric Ihren and Cecil Adams, have suggested that the false nose also contained copper. Ihren wrote that when Tycho's tomb was opened on June 24, 1901, green marks were found on his skull, indicating traces of copper. Adams also mentions a green colour change reaction during the examination of the earthly remains. Other historians have speculated that Tycho Brahe tried various prosthetics or he may have worn them alternately, possibly a copper nose was more comfortable and less heavy than one made of precious metal alloys.

Jacob de Gheyn's engraving: Tyhco Brahe - the portrait that allegedly also inspired Shakespeare

Tycho Brahe died suddenly after attending a banquet in Prague, more exactly eleven days later, on October 24 in 1601. According to Kepler's firsthand account, despite an urgent need Tycho had refused to leave the banquet to relieve himself because it would have been a breach of royal etiquette. After he had returned home he was no longer able to urinate, more precisely only in very small quantities and with unbearable pain. Before he died he got into a delirious state during which he kept repeating that he hoped he had not lived in vain. Before dying, he urged Kepler to finish the Rudolphine Tables (which Kepler finally published only in 1627) and to adopt Tycho's own system of planetary motions, rather than that of Copernicus.

Others attributed Tycho Brahe's death to a kidney stone, but the examinations performed after the exhumation in 1901 did not provide convincing evidence. The most widely accepted view today is that his death most likely resulted from uraemia[1] (chronic kidney failure).

[1] The word uraemia means 'urea in the blood'. It may be due to advanced kidney damage. Uraemia results from the inadequate excretory, regulatory and endocrine function of the kidney, thus, many different compounds that would be normally excreted in the urine accumulate in the body, their detectable concentration in the blood increases. The symptoms that often accompany this condition are fatigue, loss of appetite, nausea and itching. Without treatment uraemia may have serious consequences, even death.

But what could have caused the kidneys to stop working? Had the famous scientist got an infection? Or was he perhaps murdered?

There are various theories about who and why could have poisoned Tycho Brahe. Some say it was Christian IV of Denmark who hired an assassin - according to the proponents of this theory the famous astronomer was one of those who inspired Shakespeare's play, Hamlet. Others suspect Kepler – Kepler needed Tycho's data for his life's work, the already mentioned Rudolphine tables, however, after Tycho's death he had great difficulties getting his hands on them and spared no effort to obtain them from Tycho's family members - which seems to contradict this theory. Still others believe that a Jesuit dripped poison into Tycho's glass at the banquet.

Even if the detection of the motives is not easy four hundred years later, perhaps the fact of murder can be proved.

In 1991 scientific tests were carried out in Denmark on a few of the hairs of Brahe's moustache with the permission of the Prague National Museum, which has Brahe's moustache in its collection. The analysis of samples revealed mercury levels more than 100 times above normal.

According to an article featured on the history portal Múlt-kor[2]: 'Five years later, physicists at the University of Lund presented the results of another study, this time using a proton microprobe. It turned out that Brahe had swallowed the fatal amount of mercury about 13 hours before his death. US expert Joshua Gilder believes an assassin used mercuric chloride, which he dripped into Brahe's glass. A few drops would have been fatal.'

However, the results still have not proved convincing. Therefore, during the 2010 exhumation a group of scientists collected about 100 milligrams of bone, hair and clothing samples for analysis as well as samples from the presumed bones remains of Brahe's wife (who died three years after her famous husband). Examining these they wanted to get closer to the solution of the mystery.

(1)
In scientific procedures the evaluation of evidence is based on very strict criteria. Can it be stated with certainty whether the bone samples belonged to Tycho Brahe's wife?

Look for answers to the following questions and summarize your answers in a few sentences.
What naturally occurring elements in the human body can identify a person with certainty? What remains are used, how do scientists work during the identification process? What makes you totally certain that a bone sample comes from a specific person? (10 points)

(2)
May contamination by metallic elements released from the nose prosthesis have caused Tycho Brahe's death? Justify your answer with chemical arguments.
Look for answers to the following questions and summarize your answers in a few sentences.

[2] http://www.mult-kor.hu/cikk.php?id=22977%C2%A0&pIdx=2&print=1

What type of "green coloration" and "green colour change" can be associated with the presence of copper? (10 points)

(3)
Check it up. In what forms can mercury enter the human body? What are the symptoms of mercury poisoning? What was mercury used for in Tycho Brahe's era? Is it possible that Tycho Brahe ingested the large amount of mercury found in his body during his alchemical and iatrochemical experiments?
Write an argumentative essay (10 – 15 lines) based on your answers. (10 points)

(4)
The quoted article on Múlt-kor portal mentions mercuric chloride.
Check it up. What are the physical and chemical properties of the mercuric chloride called calomel or sublimate? Where do their traditional names come from, what do they refer to? What is the chemical name of these two compounds? What physiological effects can be connected to these mercury derivatives based on their chemical properties?
Create a chart to display your results. Using your chart write a short report about which mercuric chloride may have caused the death of Tycho Brahe. (10 points)

(5)
An investigation into the origin of chemical names can also reveal interesting correlations.

a) Which properties of mercury do the following foreign names refer to: hydrargyrum (Greek), argentum vivum (Latin), Quecksilber (German), mercury (English)?
Why could János Schuszter, the creator of the name 'higany' as mercury is known today in Hungary, have thought that this chemical element (whose earlier name 'kéneső' was the Magyarized Turkish name 'könösü') also could be called 'szerdany'? (5 points)
b) ***'Design a 'periodic business card' that refers to the origin of the name of mercury as well as to its properties.'***
The Periodic Table Printmaking Project may give you inspiration: http://www.azuregrackle.com/periodictable/table/ (5 points)

Mercury caused problems not only in the Middle Ages. Mercury compounds entering the cycles of nature impose significant risks these days.

Therefore, the United Nations and the European Union signed treaties aimed at reducing mercury emissions and minimizing the use of mercury derivatives. The United Nations Environment Programme (UNEP) Global Mercury Partnership[3] has assessed the situation regarding mercury emissions, pollution and its environmental and health aspects and has published the results in many reports (including the Global Mercury Final Report issued in Geneva in 2002). The following tasks are associated with this data.

[3] http://www.chem.unep.ch/MERCURY/Report/Final%20Assessment%20report.htm

(6)

Create a chart based on the table below, which compares the quantities of mercury from various sources. Explain why you have chosen that particular chart type for comparison. Use the completed chart to compare the amounts of mercury deriving from the various sources (exposure). (10 points)

The data come from the survey carried out by World Health Organisation (WHO) in 1990. The data are based on estimates; however, there are significant differences between countries: for example, where the consumption of marine fish is higher, the amount of methyl mercury may exceed the values listed in the table.

Table 1 *Estimated daily mercury intake and storage in body (the data in parentheses indicate the amount of mercury stored in your body) in a population with average sedentary lifestyles, not working with mercury derivatives. The data is given in μg/ day WHO/IPCS, 1991).*

Source / Exposure	**elemental mercury (mercury vapour)**	**inorganic mercury compounds**	**methyl mercury (organic mercury compounds)**
air	0.03 (0.024)*****	0.002 (0.001)	0.008 (0.0069)
amalgam dental fillings	3.8-21 (3-17)	0	0
food			
- fish	0	0.60 (0.042)	2.4 (2.3)******
- other	0	3.6 (0.25)	0
drinking water	0	0.050 (0.0035)	0
Total	3.9-21 (3.1-17)	4.3 (0.3)	2.41 (2.31)

Note: The figures in brackets are reference data for adults.

* If the concentration in urban areas were 15 ng/m^3 (for example near incinerators), the data would be 0.3 (0.24) μg / day.

** Assuming the consumption of 100 g fish per week and considering 0.2 mg / kg average mercury concentration in fish.

(7)

According to the U.S. ATSDR (Agency for Toxic Substances and Disease Registry), extremely small amount (less than 0.01%) of metallic mercury is absorbed from the body, even if it has been swallowed. However, if the same amount of mercury vapour is inhaled, about 80% of it passes into the blood stream; what is more, approx. 95% of methyl mercury (which can primarily accumulate in fish and seafood) is readily and completely absorbed by the gastrointestinal tract.
(Source: http://www.labtestsonline.hu/tests/Mercury.html)
Calculate from the above figures and tables, which is more dangerous: having amalgam dental fillings for a period of 5 years or 100 grams of sea fish intake per day? (10 points)

(8)

Some data of the US Environmental Protection Agency (EPA) are shown in the table below. When calculating the data the following average values were considered:

- - an average body weight of 72 kg was considered;
- - they calculated with 0,23 kg of fish when preparing fish food;
- - they determined that the average month has 30.44 days in it;
- - they calculated with an exposure limit of 0.1 μg/kg body weight for methyl mercury per day.

a) Do calculations again based on the above data and on a freely chosen row of the table. (For example, can the type of fish containing the amount of mercury given in line 1, Table II be consumed without any risk if the EPA guidelines are considered and we assume that the quantity of organic mercury compound found in fish is absorbed in the proportion defined in task (7)?).

b) What is the maximum weight of fish that can be consumed per month if fish tissue contains an average of 0.4 mg / kg of methyl mercury?

c) What is the maximum number of times per year that a person weighing 60 kg can eat fish if the measured concentration of methyl mercury in fish body is 0.1 ppm?

d) Create a chart based on the data in the table below. Write about how methyl mercury concentrations in fish relate to the recommended amount of fish.

e) How much mercury enters the body of a person weighing 72 kg if they consume fish containing 0.2 ppm of methyl mercury four times a month? (95% of methyl mercury is absorbed in the body.)

Based on the recommendations of EPA an exposure limit of 0.3 mg/kg body weight has been determined as the maximum methyl mercury level found in the consumed fish, crab or scallops. This data was based on 17.5 grams of fish consumption per day.

f) How does this exposure limit relate to the EPA guidelines on recommended maximum amounts of fish that people should consume. (Justify your answer, include calculations.) (20 points)

Table II The recommendations of EPA regarding consumption of fish based on amounts of methyl mercury in fish tissues (US EPA, 2001).

Maximum recommended consumption frequency of one meal per month	**Concentrations of methyl mercury in fish tissue (ppm = mg / kg wet weight)**
16	> 0.03–0.06
12	> 0.06–0.08
8	> 0.08–0.12
4	> 0.12–0.24
3	> 0.24–0.32
2	> 0.32–0.48
1	> 0.48–0.97
0.5	> 0.97–1.9
none (<0.5)*****	> 1.9

* none = should not be eaten at all

> meaning "over" (for example "> 0:06 to 0:08" means "ranging from over 0.06 to 0:08")

(9)
After studying the following table write at least ten findings in connection with mercury emissions. (10 points)

Table III Mercury emission - the percentage of total mercury emissions

Mercury emission	Coal thermal power station	Coal burning – other sources	Oil combustion	Cement production	Non-ferrous metals production	Production of pig iron and steel	Chlor-alkali compounds	Waste incineration	Other	Average of the total resources
Hg^0 (g)	0.5	0.5	0.5	0.8	0.6	0.8	0.7	0.2	0.8	0.64
Hg(II)	0.4	0.4	0.4	0.15	0.3	0.15	0.3	0.6	0.15	0.285
Hg (particle bound mercury)	0.1	0.1	0.1	0.05	0.1	0.05	0	0.2	0.05	0.075

Useful links:
http://www.nembulvar.hu/index.php?option=com_content&view=article&id=402:tycho-brahe-a-csillagasz&catid=51:gondolkodo&Itemid=92
http://www.hir24.hu/tudomany/170600/exhumaltak-tycho-brahet.html
http://hvg.hu/vilag/20101027_tycho_de_brahe_csillagasz_sir
http://csillagaszattortenet.csillagaszat.hu/egyetemes_kesokozepkor_csillagaszata/20040422_brahe.html
http://csillagaszattortenet.csillagaszat.hu/egyetemes_kesokozepkor_csillagaszata/20081028_hamlet_csillaga.html
http://www.hartnell.cc.ca.us/faculty/jhughey/Files/dnaextractionburnedbones.pdf
http://en.wikipedia.org/wiki/DNA_profiling
http://en.wikipedia.org/wiki/Forensic_archaeology
http://www.dgci.sote.hu/file.download.php?id=3332
http://www.space.com/9567-bones-danish-astronomer-tycho-brahe-yield-clues-death.html
http://www.kfki.hu/chemonet/hun/olvaso/histchem/alkem/jatro.html
http://www.kfki.hu/chemonet/hun/teazo/gyujt/elem.html
http://www.labtestsonline.hu/tests/Mercury.html
http://www.laboratoriumkft.hu/mintaveteli-es-egyeb-tajekoztato/metabolit-vizsgalati-modszerek/