The 'Baghdad Battery'

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In 1936, earth-moving operations were being carried out by Iraq State Railways on the Baghdad-Bakuba line, some 2 miles from the outskirts of Baghdad and near a series of hillocks known locally as Khuyut Rabbou'a (also transliterated as Khujut Rabu'a). On 14th June a stone slab covering an ancient burial was exposed, and this chance discovery resulted in the site being excavated by the Iraq Antiquities Department.[1] Over 600 stratified objects and fragments were recovered, including pottery and glass vessels, beads, clay figurines, and bricks engraved with symbolic characters. These enabled the site to be identified as an important settlement of the Parthian period, around 248 B.C. – 226 A.D.

The collected artefacts were transferred to the Iraq Museum, Baghdad, where in due course they were examined by Wilhelm König, then Head of the Conservation Laboratory. He was particularly intrigued by an associated group of objects found in level F IV (b), and given registration numbers IM 29209 – 29211. They are shown here in Fig. 1, and consist of:

a) An ovoid flat-bottomed pottery jar, with its upper flange broken away at the neck. Height 140 mm, max. o.d. 80 mm.

b) A roughly made tube of sheet copper, 98 x 26 mm, with one end closed by a disc of the same material.

c) A completely rusted remnant of a crudely pointed iron rod, 75 mm long.

d) Fragments of natural bitumen, with further bitumen covering the base of the interior of the copper vessel and forming a collar around the top of the rusty iron rod. Apparently, (b) and (c) were found as an assembly, with the iron rod held within the copper tube (but not in metallic contact with it) by the bitumen collar. This assembly was itself within the pottery jar.

These materials are concordant with a date between the first century B.C. and the first century A.D.: it is the function proposed for the assembly that has led to a certain notoriety.

A Primary Cell?

König[2,3] proposed that the addition of a dilute acidic electrolyte, such as vinegar or lemon juice, would cause the assembly to behave as a primary voltaic *cell*

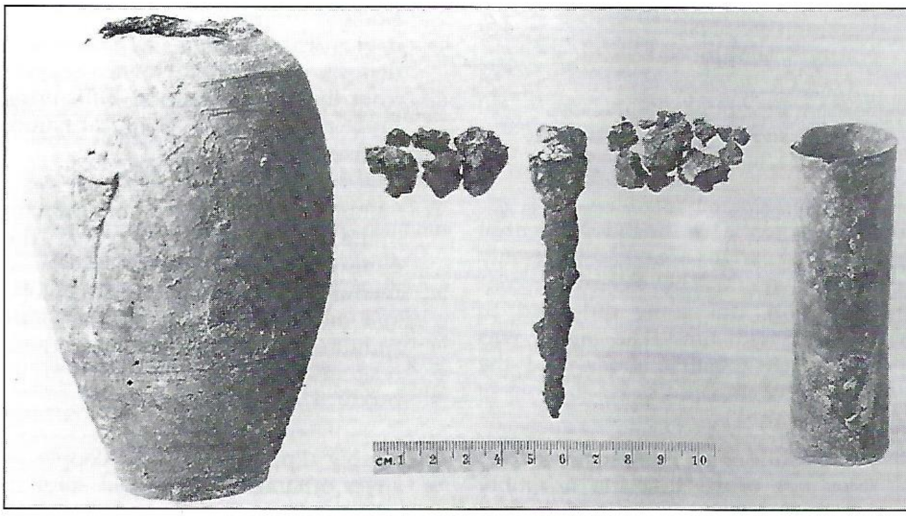

Fig.1 *The Parthian objects found in association at Khuyut Rabbou'a in 1936.*

(Fig. 2). Whether the pottery vessel was simply a support, or also served to contain the electrolyte if the copper cylinder was not watertight, is not clear. König further states that more of these assemblies had been found in excavations in Tel'Umar,[4] so goes on to suggest that a number of such cells in series would produce a *battery* of sufficient power to permit the electroplating of small copper or silver ornaments with gold. ('Battery' comes from the term applied to a fixed, side-by-side array of heavy cannon used to batter down the walls of a town during a medieval siege.)

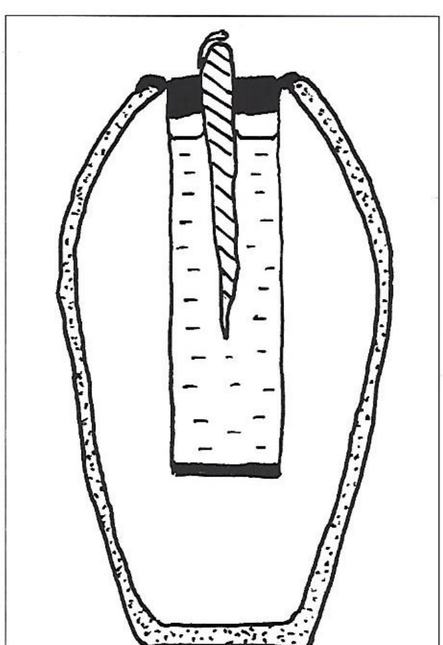

Fig.2 *König's reconstruction as a 'voltaic cell'.*

Such a function would, of course, vastly predate the generally accepted invention of the voltaic pile by Alessandro Volta[5] in 1800. The 'Baghdad Battery' was publicized by the science fiction writer Willy Ley,[6] and soon came to occupy an increasingly garbled and exaggerated place in many popular and uncritical compilations of 'marvels and mysteries from the past' – for example references 7-14. More unfortunately perhaps, it has also found its way into serious textbooks on the history of electricity and the technology of battery systems.[15,16]

Electrical Difficulties

König's reconstruction of the object as a voltaic cell faces a number of technical objections that are not mentioned in the articles referenced above:

a) There is no supporting written evidence for such a device within its culture, nor hints from other societies.

b) No 'connecting wire' was associated with it. A bare metallic wire would serve, but as these had been drawn from copper and precious metals from very ancient times a deliberately insulated wire (e.g. wrapped with cloth and bitumen) would be more persuasive.

c) Any pair of dissimilar metals dipping into an electrolyte will generate a potential difference (P.D.) between themselves.[17,18] – Electrodes of freshly abraded copper and iron were placed in the following aqueous electrolytes and the P.D. between them measured with an electrometer[19]:

Electrolyte	*mV*
Acetic acid (5%)	540
Citric acid	490
Common salt, NaCl	440
Natron[20], sodium carbonate Na_2CO_3	56
Sodium bicarbonate $NaHCO_3$	10
Trona[20], sodium sesquicarbonate, $Na_2CO_3.NaHCO_3$	4

These potentials were independent of electrode surface area, and were only slightly affected by electrolyte concentration, but some did tend to decrease with time. The copper was always the positive *anode*, and the iron the negative *cathode*.

Demonstration of this phenomenon[15] does not prove that the assembly under discussion was ever intended as an electrochemical cell.

d) Copper/zinc is a more effective couple than copper/iron. Experimental tests with these metals in 5% acetic acid give a P.D. of 580mV. It was found in ancient times that zinc is much easier to smelt from its ores than iron, so if the device was intended to produce a P.D. why was the latter preferred?

e) 5 separate Cu/Fe cells with 2" x 1" electrodes (spaced 0.25" apart) dipping into 5% acetic acid were connected in series to produce a battery. It registered a P.D. of 2.6 volts on the electrometer – essentially open circuit. However, as soon as a nominal 2.5 v torch bulb (7.5 ohm resistance) was placed across the terminals the P.D. fell precipitously to near zero: the battery was utterly incapable of causing the lamp to so much as glow.[21] An external resistance of 1000 ohms permitted a long-term current of no more than 120μA and a P.D. of 300 mV, the iron becoming discoloured and rusty.

This phenomenon is known as *polarization*.[22] It is believed to be due to a local diffusion-limited fall in concentration of oxidizing ions in the vicinity of the anode. A one-time empirical remedy still used today in the very successful Leclanché cell is packing manganese dioxide around the anode.[16] It acts as a *depolarizer*.

Electroplating only became practicable in the late 1860s with the invention of the polarization-resistant Daniell cell[23], soon supplanted by the dynamo.

Gilding of Copper and Silver

Gilded jewellery is known from early times, and was the major reason for König's proposal that the Baghdad device was used for electrochemical deposition of gold. However, apart from the above electrical difficulties, problems of a more chemical nature then arise:

f) Solubilization of gold is very difficult – the reason for its 'nobility'. The element is dissolved only by a mixture of concentrated hydrochloric and nitric acids ('aqua regia') or sodium/potassium cyanides. These reagents are generally held to be products of medieval alchemy.

g) Simply dipping a cleaned copper or silver ornament into a gold solution will produce a coating of the latter metal by *displacement*. The process ceases as soon as all the base metal has been covered, so the film is extremely thin and easily worn off. A well-known demonstration is dipping a penknife blade into acidified copper sulphate solution: a film of copper (initially an unexpected salmon pink) is deposited. 'Displacement gilding' is not a proof[12] of electrochemical plating.

Indeed, the occurrence of gilded objects in ancient times does not necessarily point to electrochemical deposition at all, for a number of alternative techniques were known:

i) Coating with 'gold leaf' secured with a resinous cement.

ii) 'Pickling': the etching of alloys of a low gold content to leave an enriched surface layer.

iii) Mercury or 'fire' gilding depends on the fact that gold filings will dissolve in elemental mercury to form a liquid alloy traditionally known as an *amalgam*. When rubbed over a clean copper or silver object it forms an adherent amalgam with them, too. Heating to some 300°C then decomposes the amalgam and drives off the mercury, leaving behind a layer of gold. There is nothing deficient about the results: it is not (legally) used today simply because the evolved mercury vapour acts as a cumulative neurotoxin.

iv) Gold decoration is still applied to glazed china and glass by painting with a colloidal suspension of gold in aromatic oils. Firing drives off the carrier and leaves the gold as an adherent shiny film.

v) Craftsmen to whom mercury was not available might still have gilded copper ornaments by briefly dipping them into the gold/copper eutectic[24] melting at *c.* 400°C, probably covering the alloy with molten resin to act as a protective flux.

The Real Purpose of the Artefact?

In 1993, Keyser[25] published by far the best evaluation of the Baghdad artefact, but still accepted that it was electrical in nature: he proposed that it was used for analgesia. I find this unlikely in view of the 'electrical' objections above, especially since it takes about 50v to be mildly detectable to the fingers, whilst 'electric fish' generate some hundreds of volts.

So what could be the purpose of the artefact? Any reconstruction of the function of an unknown object must be compatible with the way of life of its erstwhile owners, not with some fancied resemblance to a modern object – here a torch battery. Now, if you are making journeys in an arid land then water is most precious – your very survival may depend on the contents of a goatskin attached to the camel's saddle. A crack or hole could prove disastrous. I therefore wish to put forward the mundane and undramatic suggestion that it is the contained bitumen that justified carriage of the assembly described by König. In the event of a leak the iron rod was made hot in a flame (perhaps the spike was once driven into a wooden handle) plunged into the bitumen to melt off a blob, and then applied to the leaking area of goatskin. The hot rod was then returned to the copper container, which in turn was dropped into a (salvaged) pottery vessel to protect other possessions against heat and soiling.

Notes and References

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3. W. König, *Neun Jahre Irak* (Rohrer: Brünn, 1940), pp. 166-168.

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13. P. James and N. Thorpe, *Ancient Inventions* (London: O'Mara Books,1995) pp.148-152.

14. Surf the Web!

15. C.L. Mantell, *Batteries and Energy Systems* (McGraw-Hill, 1970).

16. K.V. Kordesch, ed. *Batteries. Vol. 1 Manganese Dioxide* (New York: Dekker, 1974).

17. H.J.T. Ellingham, 'Primary Cells', *School Science Rev.* **18** (1936-37), pp. 352-366.

18. P.W. Atkins, *General Chemistry* (Scientific American Books, 1989), chapter 17.

19. A transistorised voltmeter of near-infinite internal resistance.

20. *Natron* and *trona* are widely available in desert places as a result of the drying-up of ephemeral lakes. Both give alkaline solutions when dissolved in water.

21. I am therefore puzzled by the successful application of large-area (but still elementary) Cu/Zn/mineral acid batteries to high current applications (e.g. electromagnets) by Davy, Faraday and others. This matter is being pursued.

22. C.A. Vincent and B. Scrosati, *Modern Batteries: An Introduction to Electrochemical Power Sources* (Arnold, 2nd ed., 1997).

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