THE PURPOSE OF THE PARTHIAN GALVANIC CELLS: A FIRST-CENTURY A.D. ELECTRIC BATTERY USED FOR ANALGESIA*

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I. INTRODUCTION

THE Parthian galvanic cells (electric batteries) have been known for some fifty years but have never been scientifically published, have heretofore seemed embarassingly out of context, and have received little scientific treatment since their first publication. I have examined the find and some similar, probably parallel, finds and have considered how the device might have been invented and what the electrolyte might have been. The usual hypothesis, which was proposed by Wilhelm König, who first published the find, is that the purpose of the cells was electroplating, but I argue that this is impossible. Rather, I suggest a purpose, more in keeping with the technological and scientific milieu, as a substitute for the use of electric fish as a local analgesic (attested in the first century A.D. and later). Such an application is supported by the modern clinical practice of transcutaneous electrical nerve stimulation.

II. THE DISCOVERY AND DISCUSSION

More than fifty years ago the Austrian painter and director of the Baghdad Museum and Iraq Antiquities Department Wilhelm König reported the discovery of an ancient electric battery.[1] The device consists of an ovoid ceramic jar about 14 cm tall and 8 cm in diameter. In the 3.3 cm opening was set a 9.8 cm long, 2.6 cm diameter tube formed of rolled and soldered copper sheet, affixed by means of asphalt. The tube was closed at the bottom with a copper disk sealed and covered with a 0.3 cm layer of asphalt. Down the axis of the copper tube an iron rod was suspended from the upper asphalt plug; the rod was about 7.5 cm long (see fig. 1). Both copper and iron projected above the upper asphalt plug. The object was

* I am indebted to Werner Krenkel, Rostock, Germany, who first alerted me to the serious literature on these devices (Spring 1986); to the Wilhelm-Pieck Universität, Rostock, FB Anglistik, where I wrote this paper (Spring 1989); to Trevor Hodge, chair of the Archaeological Institute of America session on ancient technology at the December 1989 meeting, where I first presented this idea (see the abstract in *American Journal of Archaeology* 94 [1990]: 341), and to the Ancient Technologies and Archaeological Materials Program at the University of Illinois, Urbana-Champaign, where I was on a George A. Miller Visiting Professorship in Spring 1990, and whose assistant director, Sarah U. Wisseman, encouraged my work.

[1] W. König, "Ein galvanisches Element aus der Partherzeit?," *Forschungen und Fortschritte* 14 (1938): 8–9, and idem, *Im Verlorenen Paradies—Neun Jahre Irak* (Munich and Vienna, 1939), pp. 166–68, pl. between pp. 160–61. For biographical information, see *Neun Jahre Irak*, pp. 3–4. Wilhelm König was a member of the "Warka Expedition" of the Deutsche Orient-Gesellschaft; I have been unable to locate other biographical information.

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found by members of the Iraq Antiquities Department in the course of regular excavations in an undisturbed stratum of a Parthian settlement site (the modern Khujut Rabou^{c}a near Baghdad)[2] in association with magical bowls, and is dated to the first century B.C. or the first century A.D.[3] (below I argue for the latter).

Similar artifacts have been found elsewhere, dating to the Sasanian period, sometimes in association with magical objects. Near the ancient Seleucia-on-Tigris (40 km downstream from Baghdad), such devices, stuffed with papyrus and lacking the internal iron rod, but in close association with iron and bronze needles, were found in what appeared to be a magician's house (see fig. 2).[4] Several pottery jugs have been found at Ctesiphon (fig. 3 shows one), in each of which were cylinders of bronze, sealed at both ends and filled with organic material.[5] König considered the Seleucian and Ctesiphontine finds parallel, but the absence of the internal iron electrode elicits hesitation.

The Parthian device so closely resembles a wet-cell (i.e., galvanic cell with liquid electrolyte) that König assumed it was one. Various features of the construction point in that direction. The asphalt seal indicates the presence of liquid,[6] and almost all available liquids (save vegetable and mineral oils) were acidic. The presence of dissimilar metals in an acid generates a potential difference and is the key feature of a Voltaic pile. The otherwise useless 0.3-cm asphalt layer on the bottom would serve to prevent the possible shorting of the iron rod to the copper bottom (cf. fig. 4). Asphalt is an inert, water-resistant insulator.[7] It is indeed difficult to see what else the device could be.

But the purpose of the device, as well as its origin, has remained an enigma. König suggested electroplating, and most commentators have followed him without examining the possibility of such a discovery in the ancient context.[8] Others have doubted the likelihood of such a use or experimented with models and various electrolytes such as vinegar or copper sulfate solution.[9] These points are considered in order: origin, electroplating, and the electrolyte, all of which lead to the consideration of the purpose.

[2] Idem, "Galvanisches Element," and A. Al-Haik, "The Rabbou^{c}a Galvanic Cell," *Sumer* 20 (1964): 103–4.

[3] Rolf Stucky, in Eva Strommenger, ed., *Der Garten in Eden: 7 Jahrtausende Kunst und Kultur an Euphrat und Tigris* (Mainz am Rhein, 1978), p. 211 (no. 183). I am indebted to Max Kunze and Ralf B. Wartke of the Staatliche Museen zu Berlin for this reference and a pleasant hour of discussion.

[4] Leroy Waterman, *Preliminary Report upon the Excavations at Tel Umar* (Ann Arbor, 1931), vol. 1, pp. 61–62, pl. 12.

[5] E. Kühnel et al., *Die Ausgrabung der zweiten Ktesiphon-Expedition 1931/32* (Berlin, 1933), p. 28, pl. 45.

[6] Bitumen was, in fact, the normal Mesopotamian (cf. Strabo 16.1.9, 15) and Parthian seal. See N. C. Debevoise, *Parthian Pottery from Seleucia on the Tigris,* University of Michigan Studies, Humanistic Series 32 (Ann Arbor, 1934), p. 18, and R. J. Forbes, *Studies in Ancient Technology* (Leiden, 1964), pp. 74–80, 90–95; the Greco-Roman seal was resin (cf. Pliny 14.25). See M. Wheeler, *Rome beyond the Imperial Frontiers* (London, 1954; reprint New York, 1971), p. 149, and A. Lucas, *Ancient Egyptian Materials and Industries,* 4th ed., rev. (London, 1962), pp. 19–20.

[7] H. Winkler, "Galvani und Volta nur Wiederentdecker—Eine dringend notwendige Berichtigung," *Elektrie* 14 (1960): 71–72, here p. 72. I thank Werner Krenkel for this reference.

[8] G. Gamow, *The Birth and Death of the Sun* (New York, 1940), pp. 33–34, fig. 7; 2d ed. (New York, 1952), pp. 29–30, fig. 7; W. Ley, "The Elements of Khujut Rabu^{c}a and Ctesiphon," *Galaxy* 9/3 (December 1954): 44–51; [Anonymous], "Batteries B.C.," *The Laboratory* 25/4 (1956–57): 112–13, reprinted (with very few verbal changes) as H. M. Schwalb, "Electric Batteries of 2,000 Years Ago," *Science Digest* 41/4 (April 1957): 17–19; [Anonymous], "Kannte man schon vor 2000 Jahren galvanischen Elemente?," *Elektro-Welt. Ausgabe B. Industrielle Elektrotechnik* 4 (1959): 176; E. K. Hornauer, "Elektrische Batterien—vor 2000 Jahren," *Elektro-Nachrichten* 11/1 (1959): 15; and L. Sprague de Camp, *The Ancient Engineers* (New York, 1960; reprint Cambridge, Mass., 1970), p. 234; 2d ed. (New York, 1974), p. 252.

[9] Winkler, "Wiederentdecker," pp. 71–72; W. Winton, "Baghdad Batteries B.C.," *Sumer* 18 (1962): 86–87, pl. 1; Al-Haik, "Galvanic Cell"; Stucky, *Garten in Eden;* and [Anonymous] in *Science Digest* 90/2 (February 1982): 24.

III. POSSIBLE ORIGIN AND THE UNLIKELIHOOD OF ELECTROPLATING

It is difficult, if not impossible, to see how, on any known ancient theory of matter or its effects, the galvanic activity of dissimilar metals in an electrolyte could have been predicted. While that negative statement is difficult to prove, I should prefer to propose an accidental discovery. Had anyone ever used a bronze spoon in an iron bowl (or vice versa) containing vinegar, for example, the tingling produced in the hand or lip touching both bowl and spoon would be noticed. Such an effect might well have long remained a curiosity.

The models built[10] produce about 0.5 V at a few thousandths of an amp (compare a modern flashlight battery which produces 1.5 V at several tenths of an amp, i.e., several hundred times the power). The iron is the negative "pole" or "electrode." The voltage depends only on the two metals, while the current depends on the electrolyte. The output of the models[11] is insufficient to accomplish much in the way of electroplating.[12] These cells would have a short "shelf life" of a few weeks,[13] as the electrolyte would tend to consume the iron electrode and depolarize the cell (see below). This may explain the absence of the internal iron electrode in the later examples—perhaps they were only emplaced during actual use.

The process of electroplating is sufficiently complex that it was unlikely to be discovered accidentally. A galvanic cell is composed of two dissimilar metals in an electrolyte, and no such cell can generate sufficient voltage to reduce the more electronegative metal (here the iron of the cathode) at the surface of the more electropositive (here the copper of the anode). True electroplating occurs when a voltage is connected across two pieces of metal, i.e., the electrodes are immersed in an electrolyte capable of dissolving the metal of the anode (positive electrode) or which already contains ions of some metal in solution; in either case the dissolved metal ions plate out on the cathode (negative electrode).[14] Thus two cells would be required—the voltage-generating cell and the plating cell.

Electrodeless plating,[15] which can occur when a less noble metal is immersed in a solution of a more noble metal—iron in a copper-ion solution or copper in a gold-ion solution, for example—might have been discovered accidentally, had the ancients had any way of dissolving noble metals. Now silver will dissolve in nitric acid, and gold only in the nitric-hydrochloric acid mixture *aqua regia,* but the "mineral" acids such as these

[10] Schwalb, "Electric Batteries"; Winkler, "Wiederentdecker"; and Al-Haik, "Galvanic Cell." My own model (see below) is similar.

[11] Contra Al-Haik, "Galvanic Cell," p. 104.

[12] At 1 mA it would take about 1.1 days to plate 1gm of silver and thus would not be economically worthwhile. For Faraday's Law, and the constants used to calculate the time, see W. Blum and G. B. Hogaboom, *Principles of Electroplating and Electroforming,* 3d ed. (New York, 1949), pp. 39–40, or G. Langbein, *Electro-deposition of Metals,* 8th ed., trans. and ed. W. T. Brannt (New York, 1920), pp. 62–63.

[13] Al-Haik, "Galvanic Cell," reports eighteen days.

[14] I simplify—if the electrolyte contain metal ions, the anode typically is insoluable, carbon, platinum, or titanium being common, as is usually the case in gold plating. See Blum and Hogaboom, *Electroplating,* pp. 288–306 (gold); Langbein, *Electrodeposition,* pp. 454–69 (silver), 505–19 (gold); F. A. Lowenheim, *Modern Electroplating,* 3d ed. (New York, 1974), pp. 224–33 (gold), 358–68 (silver); or A. Watt and Arnold Philip, *The Electroplating and Electrorefining of Metals,* 2d ed. (London and New York, 1911), pp. 174–84 (gold), 227–38 (silver).

[15] Again I simplify: in true electrodeless plating the solution contains its own reducing agent and the basis metal acts only as a catalyst, while in "electrochemical replacement" the basis metal acts as both anode and cathode of the cell driving the plating. See Lowenheim, *Electroplating,* pp. 710–11 (general), 241–42 and 741–42 (gold), and 742 (silver); Blum and Hogaboom, *Electroplating,* p. 306 (gold).

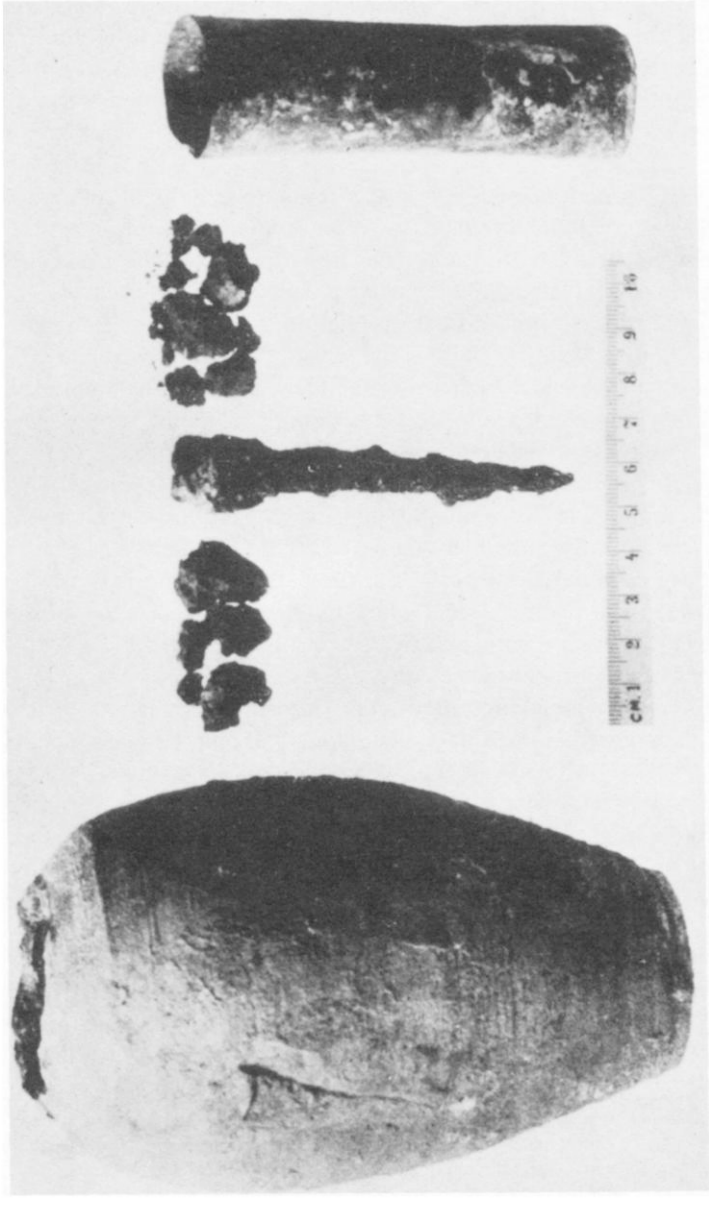

FIG. 1a.—Parthian battery from Khujut Rabou'a (after König, *Neun Jahre Irak*, pl. between pp. 160–61)

FIG. 1b.—Parthian battery from Khujut Rabou'a (after Stucky, *Garten in Eden*, pl. 183)

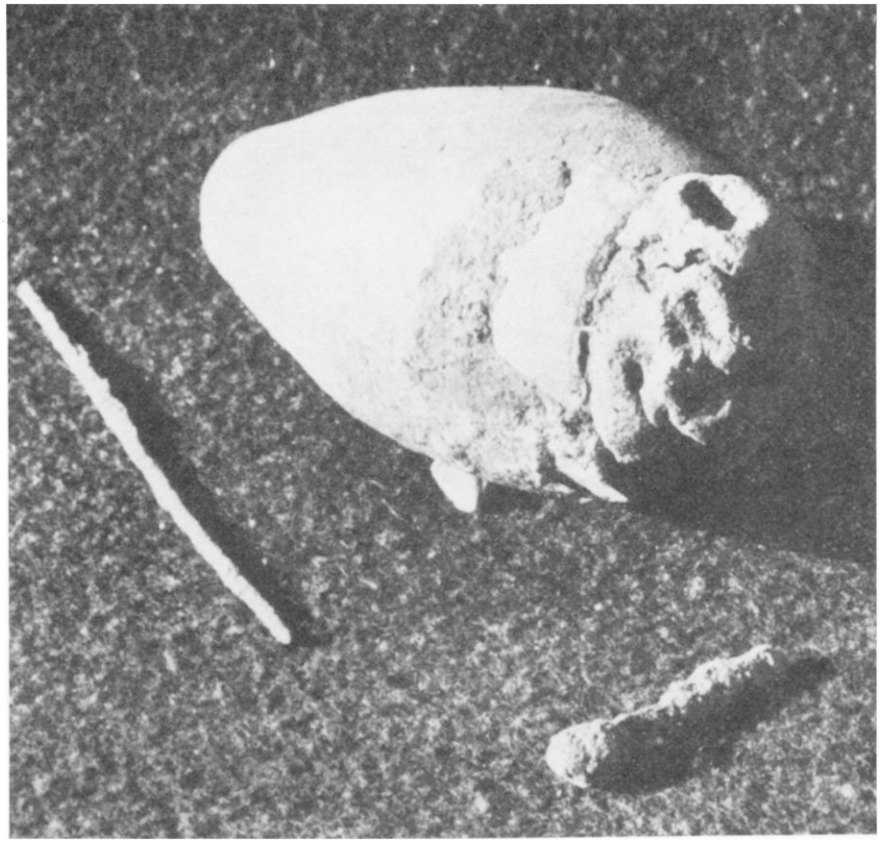

FIG. 2a.—Device from Tel Umar (after Waterman, *Excavations at Tel Umar,* pl. 12)

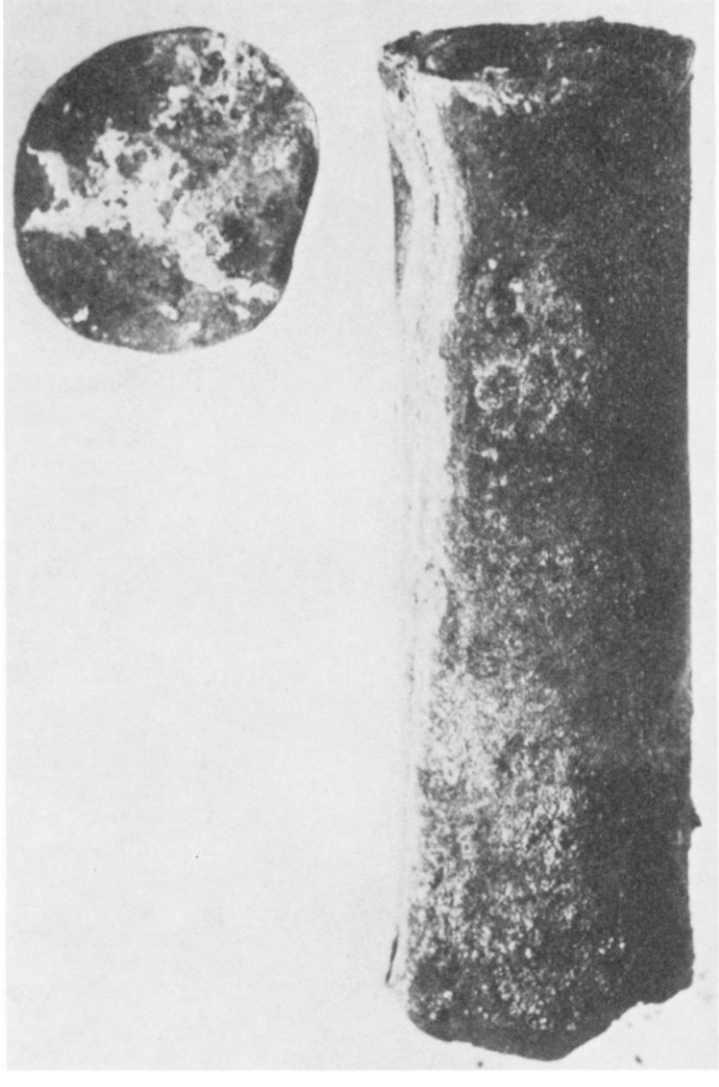

FIG. 2b.—Copper tube from Tel Umar device (after Waterman, *Excavations at Tel Umar*, pl. 12)

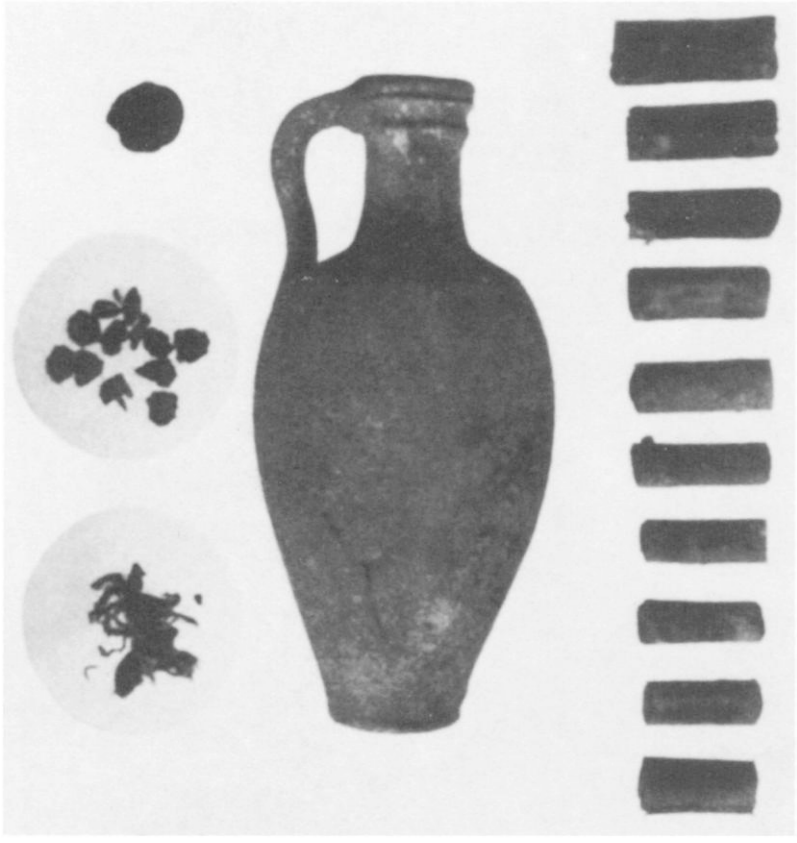

FIG. 3.—Papyrus-filled copper tubes from Ctesiphon (after Kühnel, *Ktesiphon,* pl. 45)

were not isolated before ca. A.D. 1300.[16] The complex salt-saltpeter-alum solution, which is equivalent to *aqua regia,* apparently used by the Moche Indians in Peru (first–sixth centuries A.D.) to dissolve gold and silver seems remote.[17] The dissolution of cop-

[16] E. O. von Lippmann, *Entstehung und Ausbreitung der Alchemie* (Berlin, 1931), vol. 1, s.v. Acetum (p. 3), and s.v. Mineralsäuren (pp. 146–47) and idem in ibid., vol. 3 (Weinheim, 1954), s.v. Säuren (mineralischen) (p. 119); R. J. Forbes, *Studies in Ancient Technology* (Leiden, 1965), vol. 3, p. 80; J. R. Partington, *Origins and Development of Applied Chemistry* (London, 1935), p. 486; and R. J. Forbes, "The Evolution of the Still," *Proceedings of the Chemical Society (London)* (1942): 237–42, here p. 238. On the other hand, though I remain skeptical, Reginald Campbell Thompson, *Dictionary of Assyrian Chemistry and Geology* (Oxford, 1936), pp. xxxi–vi, argues that the Assyrians perhaps did know of sulfuric acid (H_2SO_4, oil of vitriol), since they had green vitriol ($Fe_2[SO_4]_3$, pp. 89–91) and red vitriol (Fe_2O_3, pp. 97–98), and oil of vitriol can be obtained by distilling green vitriol solution (the residue being red vitriol), but the Assyrian words given by Thompson for red and green vitriol are not related (as they would be if they obtained red vitriol by this process), and Thompson can only offer "with great caution" a *hapax legomenon* of uncertain interpretation as the Assyrian word for oil of vitriol (pp. 100–104). Even so, neither silver nor gold will dissolve in sulfuric acid.

[17] H. Lechtman, "A Pre-Columbian Technique for Electrochemical Plating of Gold and Silver on Copper Objects," *Journal of Metals* 31 (1979): 154–60: note that to use the solution to plate, it must be neu-

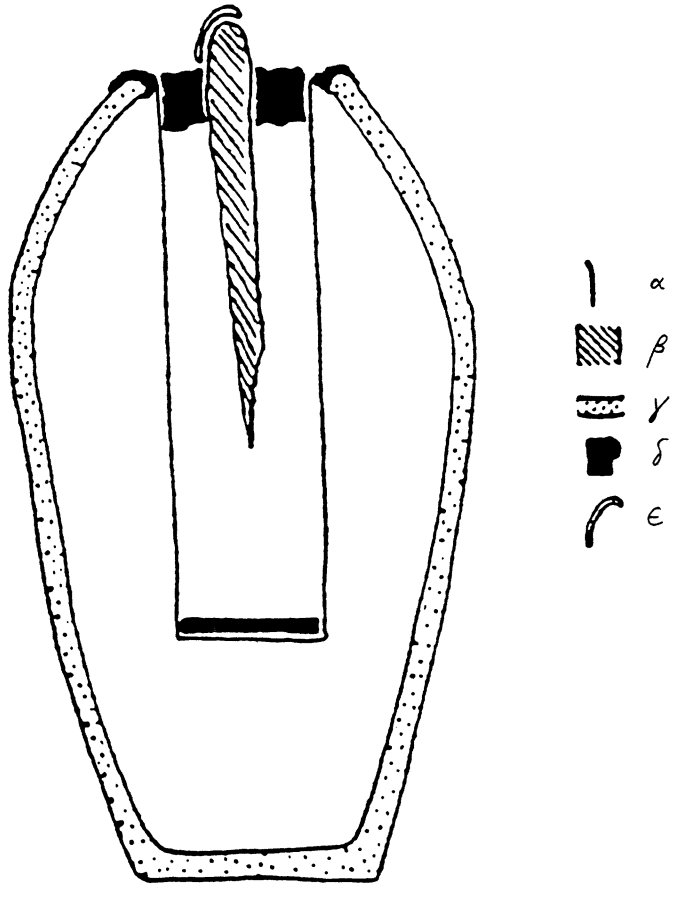

FIG. 4.—Cross-section of Parthian Battery (after König, "Galvanisches Element," fig. 2); α = Copper, β = Iron, γ = ceramic, δ = asphalt, ε = ? coating.

per in acetic acid is possible and was practiced: the product is ἰός or *aerugo/aeraca*.[18] Moreover, the alchemists report the (electrodeless) deposition of copper on iron[19] from copper sulfate solutions.[20]

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tralized with baking soda, for example. I am indebted to Michael N. Geselowitz for bringing this reference to my attention.

[18] Theophrastos *De lapidibus* 57, Vitruvius 7.12.1, Dioskorides *Materia medica* 5.79, Pliny 34.110–1. K. C. Bailey, *The Elder Pliny's Chapters on Chemical Subjects* (London, 1932), vol. 2, p. 172. Often used in medicine: cited twenty-four times in Dioskorides *Euporista*.

[19] M. P. E. Berthelot, *Collection des anciens alchimistes grecs* (Paris, 1887), vol. 1, pp. 241–42, and Langbein, *Electrodeposition*, p. 1. (I have been unable to locate the precise reference in Zosimos of Panopolis to which these authors refer.) The effect is rapid: a 10% by weight solution of $CuSO_4.5H_2O$ in water completely plated the immersed portion of a freshly cleaned iron nail in five seconds. Despite this, the cell will work with a copper sulfate solution, as my tests showed (see below).

[20] χάλκανθον; cf. Strabo 3.4.15, 16.6.5; Dioskorides *Materia medica* 5.98–99; Pliny 34.107. Strabo 3.4.15 states that he is following Poseidonios; on the

But not only is the discovery of electroplating before the development of the modern electrical and chemical theories (by Faraday, A.D. 1833)[21] extremely unlikely on theoretical grounds, there is an insurmountable practical difficulty. As just noted in connection with electrodeless plating, it was not possible to make an aquaeous solution of gold or silver in antiquity. But a solution of the metal ions to be plated is required for electroplating (as noted above). This difficulty seems not to have been appreciated by any of the commentators adopting or questioning the electroplating hypothesis. Electroplating is no more likely than electric telegraphy, for example:[22] the technological context is absent.

Furthermore, there were simple and effective methods of plating gold on silver or copper, or silver on copper, available from Sumerian times (as is shown by various plated finds).[23] One method practiced in antiquity was the etching of baser gold alloys to remove those portions of the surface composed of base metal and so leave a gold-enriched surface—"surface leaching," "surface enrichment," or "pickling"; the cementation process was applied to leach silver from a silver-gold alloy to gild the object.[24] Numismatic evidence suggests that other methods were used: silver foil eutectically fused or soldered to a copper base or dipping the base-metal coin in molten silver chloride (cerargyrite), for example.[25] The

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Pliny passage, see Bailey, *Elder Pliny,* pp. 178–80. Further on χάλκανθον, Dioskorides *Materia medica* 5.74, 79, and Galen *De simplicium medicamentorum temperamentis et facultatibus* 1.6 (11.391–92 Kühn) and 1.35 (11.442–43 Kühn) state that it is hot in nature, while 9.34 (12.238–41 Kühn) gives the method of production. It was widely used in medicine; see Dioskorides, *Euporista* 1 and 2 (twenty-three times), Galen, *De compositione medicamentorum secundum locos,* passim (12.378–13.1020 Kühn); and [Galen] *De remediis parabilibus,* passim (14.311–581 Kühn).

[21] Langbein, *Electrodeposition,* pp. 1–9; Lowenheim, *Electroplating,* pp. 1–2; and Watt and Philip, *Electrorefining,* pp. 79–98.

[22] Cf. Aischylos *Agamemnon* 8–10, 20–21, 26–30, for fire signals, and Aeneas Tacticus 31 and Polybios 10.44–45 on secret messages of other kinds (Julius Africanus, *Kestoi,* fragments 51–54 are similar). For a magisterial survey, see Hermann Diels, *Antike Technik,* 3d ed. (Leipzig, 1924; reprint Osnabrück, 1965), pp. 71–90; cf. also Forbes, *Studies in Ancient Technology,* 2d ed. (Leiden, 1966), vol. 6, pp. 171–80. The point is that there was a simpler alternative, and none of the necessary associated technology for the more complex method existed.

[23] See Partington, *Applied Chemistry,* pp. 25–26 for Egyptian gold on silver and copper; pp. 75–76 for Egyptian arsenic on copper, Metropolitan Museum inv. 26.9.12–13 (of the Fifth–Sixth Dynasty), on which see C. G. Fink and A. H. Kopp, "Ancient Egyptian Antimony [*sic*] Plating on Copper Objects," *Metropolitan Museum Studies* 4 (1933): 163–67, and Cyril S. Smith, "An Examination of the Arsenic-Rich Coating on a Bronze Bull from Horoztepe," in W. J. Young, ed., *Application of Science in Examination of Works of Art* (Boston, 1973), pp. 96–102, esp. p. 102, n. 5; Partington, pp. 230–31 for Sumerian gold on copper; p. 237 for Assyrian silver on copper; pp. 329, 361–62 for Aegean gold or silver on copper/bronze; p. 377 for Hittite silver on copper; and p. 439 for Phoenician gold on silver or bronze; Forbes, *Studies in Ancient Technology,* 2d ed. (Leiden, 1971), vol. 8, pp. 142–43; H. Blümner, *Die Technik und Technologie der Gewerbe und Künste bei Griechen und Römern,* 2d ed. (Leipzig, 1912; reprint New York, 1979), vol. 4, pp. 133–35, 308–15, 318–20; and R. Higgins, *Minoan and Mycenaean Art,* 2d ed. (New York, 1981), pl. 131 (Mycenaean tin plating).

[24] See [Demokritos] *Physika kai mystika* 12 and cf. P. Leyden X 14, 24, and 67=74. The text of [Demokritos] is published in Berthellot, *Alchimistes grecs,* vol. 1, p. 46; for the Leyden papyrus, see R. Halleux, *Les Alchimistes grecs* (Paris, 1981). On cementation, see Albert Neuburger, *Technical Arts and Sciences of the Ancients,* trans. Henry L. Brose (London and New York, 1930; reprint 1969), p. 92 (the German original is *Die Technik des Altertums* [Leipzig, 1919], [2d ed. 1921], [3d ed. 1922]); F. S. Taylor, "A. Survey of Greek Alchemy," *Journal of Hellenic Studies* 50 (1930): 109–39, here p. 130; Forbes, *Studies,* vol. 8, p. 171, 174; and H. Lechtman, "Ancient Methods of Gilding Silver—Examples from the Old and the New Worlds," in *Science and Archaeology* (Cambridge, 1971), pp. 2–30. Even in the pre-Columbian New World; see Paul Bergsøe, *The Gilding Process and the Metallurgy of Copper and Lead among the Precolumbian Indians,* trans. C. F. Reynolds, Ingeniørvidenskabelige Skrifter, ser. A, 46 (Copenhagen, 1938), pp. 35–37; and H. Lechtman, "The Gilding of Metals in Pre-Columbian Peru," in Young, *Science in Examination,* pp. 38–52.

[25] W. Campbell, *Greek and Roman Plated Coins,* American Numismatic Society Numismatic Notes and Monographs 57 (New York, 1933), pp. 144, 174; and Lawrence H. Cope, "Surface-Silvered Ancient Coins," in E. T. Hall and D. M. Metcalf, eds., *Meth-*

method of choice attested in the ancient world (at least from the first century B.C. to the first century A.D.) was mercury-amalgamation plating,[26] attested also at P. Leyden X 26 and 55. A similar process is alloying the noble metal with lead at P. Leyden X 37:[27] in both cases the noble-metal/base-metal alloy was applied to the copper and the object subsequently heated to evaporate the base metal.

IV. THE ELECTROLYTE IN THE PARTHIAN GALVANIC CELLS

Various commentators have suggested various possibilities. König imagined gold cyanide solution,[28] which is impossible, or salt water. W. Ley and H. M. Schwalb report a model containing copper sulfate solution—possible (see above),[29] although Schwalb notes that acetic or citric acids would also work and were known. The same pair of possibilities, vinegar and lemon juice, is suggested by E. K. Hornauer, followed by H. Winkler.[30] A. Al-Haik suggests wine or vinegar.[31]

There is another possibility. Already in Sumerian times distillation was practiced in Mesopotamia.[32] Experiments have been conducted with models of ancient stills,[33] which show that it was possible to concentrate acetic acid from vinegar (although it was easier to separate ethanol [grain alcohol] from water). The parallel case of the distillation of alcohol is suggestive: the evidence indicates that it was accomplished by the first century A.D.[34] Note that during this period (first century B.C.–first century A.D.) at least two instances are

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ods of Chemical and Metallurgical Investigation of Ancient Coinage, Royal Numismatic Society Special Publication 8 (London, 1972), pp. 261–78, pls. 19–20 respectively. That some or all of these were ancient counterfeits does not alter the fact that they reveal ancient plating methods. On ancient counterfeits at this period, apparently a significant problem, note Sulla's "Lex Cornelia de falsis" of 81 B.C., on which see P. Grierson, "The Roman Law of Counterfeiting," in Robert A. G. Carson and C. H. V. Sutherland, eds., *Essays in Roman Coinage Presented to Harold Mattingly* (London, 1956; reprint Aalen, 1979), pp. 240–61, here p. 242. Eutectic refers to that proportion of two metals being alloyed (here silver and copper) which has the lowest melting point (for silver and copper, the eutectic is about 70% silver, with a melting point near 780° C. See Robert C. Weast, ed., *Chemical Rubber Company Handbook of Chemistry and Physics,* 69th ed. [Boca Raton, Florida, 1988–89], p. D184).

[26] Vitruvius 7.8.4; Pliny 33.64–5, 100, 125, and 34.162–3. Blümner, *Technik und Technologie,* vol. 4, pp. 133 and 308–9, says not earlier. Pliny 34.162–63 refers to tin-plating as well; cf. P. Leyden X 41 and Halleux, "De stagnum 'étang' a stagnum 'étain'," *Antiquité classique* 46 (1977): 557–70. For the use of arsenic on copper to imitate silver, see P. Leyden X 22, 83; Taylor, "Alchemy," p. 125, and now Ian A. Carradice and S. La Niece, "The Libyan War and Coinage: A New Hoard and the Evidence of Metal Analysis," *Numismatic Chronicle* ser. 7, 148 (1988): 33–52, pls. 7–12. Mercury-gilding was also known in the pre-Columbian New World; see Bergsøe, "Gilding Process," pp. 27–28.

[27] E. R. Caley, "The Leyden Papyrus X," *Journal of Chemical Education* 3 (1926): 1149–66 and Halleux, *Alchimistes.*

[28] König, "Galvanisches Element," see fig. 3, label A.

[29] Ley, "Elements," p. 50; Schwalb, "Electric Batteries," p. 18; [Anonymous], "Batteries B.C.," pp. 112–13.

[30] Hornauer, "Elektrische Batterien," p. 15; Winkler, "Wiederentdecker," p. 72.

[31] Al-Haik, "Galvanic Cell," p. 104.

[32] M. Levey, "Evidences of Ancient Distillation, Sublimation and Extraction in Mesopotamia," *Centaurus* 4 (1955): 23–33. See also Taylor, "The Evolution of the Still," *Annals of Science* 5 (1945): 185–202; R. J. Forbes, *Short History of the Art of Distillation* (Leiden, 1948); and Levey, "The Earliest Stages in the Evolution of the Still," *Isis* 51 (1960): 31–34.

[33] A. R. Butler and J. Needham, "An Experimental Comparison of the East Asian, Hellenistic, and Indian (Gandharan) Stills in Relation to the Distillation of Ethanol and Acetic Acid," *Ambix* 27 (1980): 69–76.

[34] H. Diels, *Die Entdeckung des Alkohols,* Abhandlungen der Königlichen Akademie der Wissenschaften, Phil. hist. Kl. 5 (Berlin, 1913), reprint in his *Kleine Schriften,* ed. W. Burkert (Hildesheim, 1969), pp. 409–41; and C. Anne Wilson, *Philosophers, Iosis and the Waters of Life,* Proceedings of the Leeds Philosophical and Literary Society, Literary-Historical Section 19 (Leeds, 1984), with the review of J. Dillon, *Classical Review* n.s. 36 (1986): 35–38.

reported of inflamed wine, presumably brandy (distilled wine), as ordinary wine will not burn.[35] Moreover, both wine and soured wine (vinegar) were considered to be liquids containing the "Hot" principle[36] (in the widely accepted Four-Element theory);[37] if adding heat to one "Hot" liquid made it more efficacious, why not another? R. J. Forbes notes that vinegar was the only strong acid in antiquity,[38] and there is some Assyrian evidence of an especially strong form, i.e., possibly distilled vinegar.[39] Thus I would suggest that besides citric acid and vinegar, distilled vinegar was also possible and even likely.

My own tests showed that a salt solution (i.e., NaCl at ca. 10%) rapidly corroded the iron, depolarizing the cell so that the voltage dropped to ca. 0.4 V within less than one minute; χάλκανθον (copper sulfate solution, 10% by volume) produced about 0.45 V for several hours only, until the accumulation of copper on the iron depolarized the cell. Citric acid in the form of freshly squeezed grapefruit juice and acetic acid (glacial acetic acid diluted to 25%, 36%, and 50% by volume) produced 0.49 V, with slow depolarization (all voltages are ± 0.03 V).

V. POSSIBLE MEDICAL PURPOSE

The suggestion of a medical purpose for this device is not based on a deduction since we lack the evidence, but on an induction, as any attempt to determine the purpose of any archaeological artifact in the absence of clear parallels and literary attestation must be. Such an induction or intuition must remain hypothetical until further confirming evidence is forthcoming. Any such suggestion must take into account the complete context (archaeological, cultural, and technological) of the device and must also account for its electrical parameters.[40]

Parthia, though having its own sources of cultural strength, was surely a buffer state between the Romans and the Indian and Chinese realms.[41] The Roman trade with Parthia

[35] See Pliny 14.62 and Suetonius *Augustus* 34.5. I would like to thank Werner Krenkel for pointing out these passages to me (personal communication, 13 November 1989).

[36] Aristotle, *Meteorologika* 4.7 (384a12–14) with I. Düring, *Aristotle's Chemical Treatise: Meteorlogica, Book IV* (Göteborg, 1944), p. 45 (wine and vinegar are mostly water); *Meteor.* 4.10 (388a29–8b9) with Düring, pp. 54–55 (wine and vinegar = water + earth); *Meteor.* 4.10 (389a7–11) with Düring, pp. 56 (wine and vinegar are mostly water and congeal in the cold); *Meteor.* 4.11 (389a24–29) with Düring, pp. 56 (wine contains foreign heat; and *Meteor.* 4.11 (389b7–18) with Düring, pp. 57 (earth + water substances are hot).

[37] See my article "Horace *Odes* 1.13.3–8, 14–16: Humoural and Aetherial Love," *Philologus* 133 (1989): 75–81, here p. 76.

[38] See n. 16 above.

[39] Thompson, *Assyrian Chemistry,* p. xx: A.GEŠTIN.NA = "water of wine" (vinegar) and A.GEŠTIN.NA.KALAG.GA = "strong water of wine" (possibly distilled vinegar). Cf. also Galen *Pro puero epileptico* 6 (11.374–78 Kühn), where vinegar is strengthened by heating (though he does not refer to an ἄμβιξ = still).

[40] König, *Neun Jahre Irak,* p. 167, Ley, "Elements," p. 50, and Winkler, "Wiederentdecker," p. 72, also mention the possibility of a medical use but provide no supporting discussion and prefer the electroplating solution.

[41] In general, see G. Rawlinson, *The Sixth Great Oriental Monarchy, or, the Geography, History and Antiquities of Parthia* (London, 1873) and N. C. Debevoise, *Political History of Parthia* (Chicago, 1938). F. Hirth, *China and the Roman Orient* (Leipzig and Shanghai, 1885; reprinted New York, 1966), pp. 35–43, gives translations of Chinese texts for the first century B.C. to the second century A.D.; see discussion pp. 137–73, 207–28; for the view from the west, see G. Coedès, *Textes d'auteurs grecs et latins relatifs à l'Extrême-Orient* (Paris, 1910; reprint Chicago, 1979), pp. 2–26 for the first century B.C. to the first century A.D.; pp. 26–71 for Ptolemy. For Roman-Parthian relations during the same period, see *Cambridge Ancient History* (Cambridge, 1932), vol. 9, pp. 588–613; vol. 10 (1934), pp. 47–51, 254–59; and vol. 11 (1936), pp. 104–30; R. H. McDowell, *Coins from Seleucia on the Tigris,* University of Michigan Studies, Humanistic Series 37 (Ann Arbor, 1935), pp. 177–81, 206–31; P. J. Junge in *Real-Encyclopädie*

passed through Dura-Europus and Palmyra[42] and from there to Seleucia along the Silk Road.[43] Influence passed from Rome to China and back,[44] making Seleucia an entrepôt for East-West trade in ideas as well as goods.[45] From A.D. 43 the city shows a greater predominance of Oriental influence.[46] Medical influence passed from Rome to China with the drug trade: storax = suho, frankincense = hsülu, henna = chia-chia, theriaca = tiyehka.[47] That the devices are found in Seleucia and merely 40 km north suggests that their use and purpose might be sought in the marriage of Chinese and Roman ideas on fertile Mesopotamian soil.

Mesopotamian medical practice included a number of elements conducive to the reception of an electrotherapeutic device of this sort. In Akkadian and Babylonian medicine, following the normative Sumerian practice, two "colleges" of physicians were recognized—the *asû* and the *āšipu*.[48] The *asû* was responsible for prescriptions and incantations, which were formulaic and traditional (the wording is unchanged over a millennium),[49] and he was considered a craftsman or technician and was associated with magicians;[50] the devices were found in magical contexts. The *āšipu*, on the other hand, practiced divination and diagnosis from the patient's symptoms, but not therapy, and gained status over the *asû* in Late Babylonian times.[51] The Mesopotamian therapy was typically non-invasive,[52] using drugs in preference to surgery: one common drug com-

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der klassischen Altertumswissenschaft 18/4 (1949): 1984–86, s.v. Parthia IIA; W. Schur in *Real-Encyclopädie der klassischen Altertumswissenschaft* 18/4 (1949): 1990–2021, s.v. Parthia IIB; Karl-Heinz Ziegler, *Die Beziehungen zwischen Rom und dem Partherreich* (Wiesbaden, 1964), pp. 20–96; M. A. R. Colledge, *The Parthians* (London, 1967), pp. 21, 32–33, 78–81, 84, 109, 166–67; and H. Volkman in *Der Kleine Pauly* 4 (1972), s.v. Parthia.

[42] M. I. Rostovtzeff, *Caravan Cities,* trans. D. and T. Talbot Rice (Oxford, 1932) (a revised edition of *O Blijnem Vostoke* [Paris, 1931]), pp. 31–32.

[43] C. C. Seligman, "Roman Orient and Far East," *Antiquity* 11 (1937): 5–30; Debevoise, *History of Parthia,* pp. 42–43, 205–6.

[44] See J. Needham, *Science and Society in China* (Cambridge, 1954), vol. 1, pp. 174, 181–82, 191–92, 196–97, 233, 236–37, for Chinese influence on Rome via Parthia; for the reverse, see Seligman, "Roman Orient," pp. 15–17, 25–26; Debevoise, *History of Parthia,* pp. 86–87; idem, *Parthian Pottery,* p. 34; and, for a fascinating story as well, Homer H. Dubs, *A Roman City in Ancient China,* China Society Sinological Series 5 (London, 1957). F. J. Teggart, *Rome and China* (Berkeley, 1939; reprint 1969), gives a comprehensive survey of war and trade as they affected Rome and China in late first century B.C. to the end of the first century A.D.; Wilfred H. Schoff, *Early Communication between China and the Mediterranean* (Philadelphia, 1921) discusses the trade route; J. Ferguson, "China and Rome," *Aufstieg und Niedergang der Römischen Welt,* pt. 2, vol. 9/2 (1978): 581–603; and Manfred G. Raschke, "New Studies in Roman Commerce with the East," *Aufstieg und Niedergang der Römischen Welt,* pt. 2, vol. 9/2 (1978): 604–1361.

[45] Hirth, *Roman Orient,* lists Roman trade goods flowing east; glass, gems, textiles; see pp. 228–60.

[46] Debevoise, *Parthian Pottery,* p. 9; Tacitus *Annals* 11.8–9, recounts the recapture of Seleucia in A.D. 43 after a seven-year revolt.

[47] Hirth, *Roman Orient,* pp. 263–72, 276–79.

[48] Georges Conteneau, *La Médecine en Assyrie et Babylonie,* La Médecine à travers le temps et l'espace 2 (Paris, 1938), pp. 30–45; A. Leo Oppenheim, "Mesopotamian Medicine," *Bulletin for the History of Medicine* 36 (1962): 97–108 on pp. 102–6; Edith K. Ritter, "Magical-Expert (= *āšipu*) and Physician (= *asû*): Notes on Two Complementary Professions in Babylonian Medicine," in *Studies in Honor of Benno Landsberger on His Seventy-Fifth Birthday (April 21, 1965),* Assyriological Studies 16 (Chicago, 1966), pp. 299–321; I thank Doug Parker, Boulder, Colorado for this reference); Robert Biggs, "Medicine in Ancient Mesopotamia," *History of Science* 9 (1969): 94–105, here pp. 98–99; A. Leo Oppenheim, *Ancient Mesopotamia: Portrait of a Dead Civilization,* revised by Erica Reiner (Chicago and London, 1977), pp. 290–96.

[49] Biggs, "Medicine," p. 99; Oppenheim, "Medicine," p. 101; idem, *Mesopotamia,* pp. 290–91.

[50] Biggs, "Medicine," p. 98; Oppenheim, "Medicine," pp. 103, 106; idem, *Mesopotamia,* p. 295.

[51] Conteneau *Médecine,* pp. 94–103, 130–33, 169–76; Biggs, "Medicine," pp. 98–99; Oppenheim, *Mesopotamia,* pp. 294, 296.

[52] Oppenheim, "Medicine," p. 102; idem, *Mesopotamia,* p. 293; M. Levey, *Chemistry and Chemical Technology in Ancient Mesopotamia* (Amsterdam, 1959), p. 155; Conteneau, *Médecine,* pp. 31, 177–95.

ponent was vinegar.[53] Little is known of Parthian medicine, but it likely included most of the traditional elements of Mesopotamian medicine;[54] the Chaldean tradition continued under the Greeks,[55] and the Parthians typically tolerated local rulers and customs.[56]

Little is known of Chinese medicine during the Han period, which is nearly coterminous with the Parthian era,[57] but acupuncture was already a standard practice since at least the Chou Dynasty (i.e., before the Han). Acupuncture is described in the *Huang Ti Nei Ching* (the *Yellow Emperor's Classic of Internal Medicine*), variously dated, but no later than the first century A.D.[58] This may explain the fact that bronze and iron "needles" are found with the Seleucian devices.

The critical stimulus was, I believe, provided by the Greco-Roman use of electric fish as an analgesic. In the mid-first century A.D. (ca. A.D. 47–48), Scribonius Largus[59] first records the practice of applying the *torpedo ocellata*[60] as an analgesic for headache (*Compositiones* 11) and gout (*Compositiones* 162). The recipe for gout indicates the method:

Ad utramlibet podagram torpedinem nigram uiuam, cum accesserit dolor, subicere pedibus oportet tantibus in litore non sicco, sed quod alluit mare, donec sentiat torpere pedem totum et tibiam usque ad genua. hoc et in presenti tollit dolorem et in futurum remediat.

[53] Forbes, *Studies,* vol. 3, p. 80. Note that some medicinal vinegar was distilled from the root of *Cyperus papyrus* (L.) and that the Seleucian and possibly the Ctesiphontine devices contained leaves of papyrus. Is there some connection? Papyrus was first used as a writing material in Parthia during about the first century A.D. See Rawlinson, *Sixth Oriental Monarchy,* pp. 424–25 citing Pliny 13.73: "nuper et in Euphrate nascens circa Babylonem papyrum intellectum est eundem usum habere chartae: et tamen adhuc malunt Parthi uestibus litteras intexere" ("Recently, it has been learned that the papyrus which grows in the Euphrates around Babylon can also be used for paper, and nevertheless the Parthians still prefer to weave their letters in tapestries").

[54] For a parallel survival, see O. Neugebauer, "Survival of Babylonian Methods in the Exact Sciences of Antiquity and the Middle Ages," *Proceedings of the American Philosophical Society* 107 (1963): 528–35.

[55] J. Bidez, "Les Ecoles chaldéenes sous Alexandre et les Séleucides," *Brussels, Université Libre, Institut de Philologie et d'Histoire Orientales et Slaves, Annuaire* 3 (1935): 41–89, who writes primarily of astrology; for alchemy see pp. 75–76, 85.

[56] Debevoise, *History of Parthia,* pp. 145, 154–56, 164–66, 203–4, speaks of a breakdown in central authority; Rawlinson, *Sixth Oriental Monarchy,* makes local rule a matter of policy (pp. 88–89).

[57] J. Needham, *Science and Society in China,* vol. 6, sec. 44 (Medicine) is not yet (1992) published. In the meantime, see K. Chmin Wong and Wu Lien-teh, *History of Chinese Medicine,* 2d ed. (Shanghai, 1936); A. Chamfrault and Ung Kan Sam, *Traité de médecine chinoise,* 5 vols. (Angoulême, 1954–63), vol. 2 translates the *Nei Ching;* J. Needham et al., *Clerks and Craftsmen in China and the West* (Cambridge, 1970), pp. 260–93 and 340–78 (= "Hygiene and Preventative Medicine in Ancient China," *Journal of the History of Medicine and Allied Sciences* 17 [1962]: 429–78); and Guido Majno, *The Healing Hand: Man and Wound in the Ancient World* (Cambridge, Mass., 1975), pp. 228–59 (see pp. 450–53, extensive bibliography). I once again thank Werner Krenkel for this reference. See also Paul U. Unschuld, *Medicine in China: A History of Ideas* (Berkley, 1985) and idem, *Medicine in China: A History of Pharmaceutics* (Berkeley, 1986). I thank Robert D. Biggs for these last two references.

[58] Wong and Lien-teh, *Chinese Medicine,* pp. 44–45, 81, 87, 227–28, 236; P. Huard and M. Wong, "Histoire de l'acupuncture chinoise," *Société des Etudes Indochinoises, Bulletin* n.s. 34 (1959): 403–23; see pp. 404–5; idem, *La Médecine chinoise* (Paris, 1964), pp. 11–31; and Lu Gwei-djen and J. Needham, "Records of Diseases in Ancient China," in D. Brothwell and A. T. Sandison, eds., *Diseases in Antiquity* (Springfield, Illinois, 1967), pp. 222–37; see p. 233.

[59] S. Sconocchia, *Scribonii Largi Compositiones* (Leipzig, 1988), pp. v–vii for discussion of date.

[60] For history, see Emil Heinrich du Bois-Reymond, *Quae apud veteres de piscibus electricis extant argumenta* (Berlin, 1843), I am grateful to the Inter-Library Loan Office of Norlin Library, University of Colorado, for obtaining a copy of this from the National Library of Medicine; G. Wilson, "On the Electric Fish as the Earliest Electric Machines Employed by Mankind," *Edinburgh New Philosophical Journal* 6 (1857): 267–88; Otto Keller, *Die Antike Tierwelt* (Leipzig, 1913), vol. 2, pp. 377–78, fig. 124 (facing p. 392); P. Kellaway, "The Part Played by Electric Fish in the Early

For any sort of podagria (foot-gout): when the pain comes on, it is good for one to put a living black torpedo-fish under his feet while standing on a beach (not dry but one on which the sea washes), until he feels that his whole foot and shank are numb just up to the knees. This will both relieve the current pain and alleviate future recurrences.

The numbing effect had long been known.[61] The ability of the electric ray to transmit its discharge was reported by Heron and Pliny in the late first century A.D.[62] Heron even singles out as conductors iron and bronze, just the materials used in the cell and the needles. The transmission of the discharge was probably known earlier.[63]

Electric fish of one species or another are found in the Mediterranean and in the Nile but not in the Persian Gulf or the Tigris-Euphrates system. Is it possible that some Parthian *asû* began applying the long-known galvanic tingling produced by dissimilar metals in an electrolyte, perhaps with conductive acupuncture needles of bronze and iron, as a substitute for the Greco-Roman ichthyoelectroanalgesia?

Modern medical practice provides an instructive parallel.[64] First it must be noted that the current produced in the cell models (ca. 1 milliamp [mA]) is readily detectible on the skin or tongue and especially in cuts or punctures.[65] Since the publication of R. Melzack and P. D. Wall's "Gate Theory of Pain" twenty-five years ago,[66] electrically induced analgesia (and anaesthesia) has been subjected to an increasing number of successful clinical tests.[67]

History of Bioelectricity and Electrotherapy," *Bulletin for the History of Medicine* 20 (1946): 112–37; D'Arcy Wentworth Thompson, *A Glossary of Greek Fishes,* St. Andrew's University Publications 45 (London, 1947), s.v. "Narké" (pp. 169–72); K. Kane and A. Taub, "A History of Local Electrical Analgesia," *Pain* 1 (1975): 125–38 on pp. 125–26; *Encyclopaedia Britannica,* 15th ed., s.v. electric catfish, *Malapterus Electricus; Encyclopaedia Britannica,* 15th ed., s.v. electric ray, *Torpedo Nobiliana* is the Greco-Roman ray. For biology, see H. Grundfest, "The Mechanism of Discharge of the Electric Organs in Relation to General and Comparative Electrophysiology," *Progress in Biophysics* 7 (1957): 1–85, and H. W. Lissman, "On the Function and Evolution of the Electric Organs in Fish," *Journal of Experimental Biology* 35 (1958): 156–91.

[61] Plato *Meno* 80A, C, 84B–C; Aristotle *Historia animalium* 9.37 (620b19–23); Varro *Lingua latina* 5.12 (p. 77); and Cicero *Natura deorum* 2.127. For further literature both ancient and modern, see A. S. Pease, *M. Tulli Ciceronis De Natura Deorum* vol. 2 (Cambridge, Mass., 1958), ad loc (p. 878).

[62] Heron *Pneumatika* 1. *praef.* (p. 26 Schmidt) and Pliny 32.7. See my article "Suetonius *Nero* 41.2 and the Date of Heron Mechanicus of Alexandria," *Classical Philology* 83 (1988): 218–20.

[63] Kellaway, "Electric Fish," pp. 118–19.

[64] For a review of the early modern (to ca. A.D. 1945) results, see Sidney Licht, "History of Electrotherapy," in Sidney Licht, ed., *Therapeutic Electricity and Ultraviolet Light,* 2d ed., Physical Medicine Library 4 (Baltimore, 1967), pp. 1–70; Kane and Taub, "Electrical Analgesia," review to A.D. 1975; J. C. Serrato, "Pain Control by Transcutaneous Nerve Stimulation," *Southern Medical Journal* 72 (1979): 67–71, discusses recent results; see also L. A. Geddes, "A Short History of the Electrical Stimulation of Excitable Tissue, Including Electrotherapeutic Applications," *The Physiologist* 27 (1984): 1–47; and Robert O. Becker and Andrew A. Marino, *Electromagnetism and Life* (New York, 1982), pp. 196–203.

[65] Asher R. Sheppard and Merril Eisenbud, *Biological Effects of Electric and Magnetic Fields of Extremely Low Frequency* (New York, 1977), sec. 4, p. 24: "At cuts or needle puncture . . . [the] current at perception . . . [is] almost too small to measure", < 1 μA; "[on] tongue . . . the current at perception . . . [is] 43 μA dc, average, 4.0 μA dc minimum; "[on] forearm . . . [the] current at perception . . . [is] 50 μA dc.

[66] R. Melzack and P. D. Wall, "Pain Mechanism: A New Theory," *Science* 150 (1965): 971–81.

[67] Already before Melzack-Wall, Hans Haferkamp, and Werner Tiegel, *Die heutige Stand der Elektroakupunktur,* Schriftenreihe, Zentralverband der Ärtze für Naturheilverfahren 7 (Hamburg, 1961) and James D. Hardy, L. W. Fabian, M. D. Turner, "Electrical Anesthesia for Major Surgery," *Journal of the American Medical Association* 175 (1961): 599–600. Thereafter, a select list is all that can be given. For anesthesia, see E. G. Dimond, "Acupuncture Anesthesia: Western Medicine and Chinese Traditional Medicine," *Journal of the American Medical Association* 218 (1971): 1558–63, and Herbert L. König et al., *Biologic Effects of Environmental Electromagnetism* (New York, 1981), pp. 242–45; for analgesia, Charles Burton and D. Maurer, "Surface Electrical Stimulation (Transcutaneous) for the Relief of Pain," in J. G. Llaurado; A. Sances, Jr.; J. H. Battoclettis, eds., *Biologic*

The electrical parameters vary but for (partial) local analgesia are a current of roughly a few milliamps at a voltage of a few volts (and both direct current and alternating current up to 700 Hz are used): such analgesia might well have been produced by a device such as the Parthian cell. Three other effects have been investigated with clinical success in modern times as well: (1) trauma healing and antisepsis,[68] involving currents of 0.2 to 1.0 mA, voltages of 0.8 to 1.4 V, direct current; (2) bone regeneration,[69] involving currents of 0.001 to 1.0 mA, voltages of about 1 V, and direct current (or alternating current up to 1

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and Clinical Effects of Low-Frequency Magnetic and Electric Fields (Springfield, Illinois, 1974), pp. 231–40; Kane and Taub, "Electrical Analgesia"; Serrato, "Pain Control"; V. M. Frampton, "Pain Control with the Aid of Transcutaneous Nerve Stimulation," *Physiotherapy* 68 (1982): 77–81; T. Lundeberg, "Electrical Stimulation for the Relief of Pain," *Physiotherapy* 70 (1984): 98–100; John Miles, "Electrical Stimulation for the Relief of Pain," *Annals, Royal College of Surgeons (London)* 66 (1984): 108–12; M. R. Gersh and S. L. Wolf, "Applications of Transcutaneous Electrical Nerve Stimulation in the Management of Patients with Pain: State-of-the-art Update," *Physical Therapy* 65 (1985): 314–35; G. B. Langley, "Transcutaneous Electrical Nerve Stimulation (TNS) and Its Relationship to Placebo Therapy: A Review," *New Zealand Medical Journal* 100 (1987): 215–17; and Gary J. Ordog, "Transcutaneous Electrical Nerve Stimulation versus Oral Analgesic," *American Journal of Emergency Medicine* 5 (1987): 6–10. More recently, on animals, see Guang-Zhao Zhou and Guei-fan Xi, "Comparison between Transcutaneous Stimulation Analgesic Effect and Electroacupuncture Analgesic Effect in Rabbits," *Acupuncture and Electrotherapeutics Research* 11 (1986): 119–25. See the recent review by Maria Reichmanis, "Electroacupuncture," in Andrew A. Marino, ed., *Modern Bioelectricity* (New York and Basel, 1988), pp. 757–82.

[68] K. T. Wu, C. Dennis, P. N. Sawyer, "Effects of Electrical Currents and Interfacial Potentials on Wound Healing," *Journal of Surgical Research* 7 (1967): 122–28; D. Assimacopoulos, "Wound Healing Promotion by the Use of Negative Electrical Current," *American Surgeon* 34 (1968): 423–31; L. E. Wolcott, P. C. Wheeler, B. A. Rowley, "Accelerated Healing of Skin Ulcers by Electrotherapy: Preliminary Clinical Results," *Southern Medical Journal* 62 (1969): 795–801; B. A. Rowley, "Electrical Current Effects on *E. Coli* Growth Rates," *Proceedings of the Society for Experimental Biology and Medicine* 139 (1972): 929–34; D. B. Harrington, R. Meyer, Jr., R. M. Klein, "Effects of Small Amounts of Electric Current at the Cellular Level," *Annals of the New York Academy of Sciences* 238 (1974): 300–306; B. A. Rowley et al., "The Influence of Electrical Current on an Infecting Microorganism in Wounds," *Annals of the New York Academy of Sciences* 238 (1974): 543–51; W. R. Grant and P. F. Gatens, Jr., "Use of Low Intensity Direct Current in Management of Ischemic Skin Ulcers," *Physical Therapy* 56 (1976): 265–69; J. J. Konikoff, "Electrical Promotion of Soft Tissue Repairs," *Annals of Biomedical Engineering* 4 (1976): 1–5; O. M. Alvarez et al., "The Healing of Superficial Skin Wounds Is Stimulated by External Electrical Current," *Journal of Investigative Dermatology* 81 (1983): 144–48; Jesse J. Barron, Wyman E. Jacobson, Greg Tidd, "Treatment of Decubitus Ulcers: A New Approach," *Minnesota Medicine* 68 (1985): 103–6; N. Annal, "Negatively Charged Nature of Some Viruses and Toxins forms the Basis for Direct Current Therapy," *Medical Hypotheses* 24 (1987): 291–92; M. G. Dunn et al., "Wound Healing Using a Collagen Matrix: Effect of DC Electrical Stimulation," *Journal of Biomedical Materials Research* 22 (1988): 191–206; and C. S. Chu et al., "Therapeutic Effects of Silver Nylon Dressings with Weak Direct Current on Pseudomonas aeruginosa-infected Burn Wounds," *The Journal of Trauma* 28 (1988): 1488–92.

[69] I. Yasuda, W. Noguchi, T. Saka, "Dynamic Callus and Electrical Callus," *Journal of Bone and Joint Surgery,* ser. A, 37 (1955): 1292–93; C. A. L. Bassett, R. J. Pawluk, R. O. Becker, "Effects of Electrical Currents on Bone *in Vivo*," *Nature* 204 (1964): 652–54; B. T. O'Connor et al., "Effects of Electric Current on Bone *in Vivo*," *Nature* 222 (1969): 162–63; L. S. Lavine, I. Lustrin, M. H. Shamos, "Experimental Model for Studying the Effect of Electric Current on Bone *in Vivo*," *Nature* 224 (1969): 1112–13; T. Andrews and Z. B. Friedenberg, "*In Vivo* Bone Reactions to Varying Direct Currents," *Journal of Bone and Joint Surgery,* ser. A, 52 (1970): 600; D. D. Levy, "Induced Osteogenesis by Electrical Stimulation," *Journal of the Electrochemical Society* 118 (1971): 1438–42; L. S. Lavine et al., "Electric Enhancement of Bone Healing," *Science* 175 (1972): 1118–21; Lavine et al., "Clinical and Ultrastructural Investigations of Electrical Enhancement of Bone Healing," *Annals of the New York Academy of Sciences* 238 (1974): 552–63; D. D. Levy, "A Pulsed Electrical Stimulation Technique for Inducing Bone Growth," *Annals of the New York Academy of Sciences* 238 (1974): 478–90; H. J. Hambury et al., "Interdisciplinary Approaches in Electrically Mediated Bone Growth Studies," *Annals of the New York Academy of Sciences* 238 (1974): 508–18; Z. B. Friedenberg and C. T. Brighton, "Electrical Fracture Healing," *Annals of the New York Academy of Sciences* 238 (1974):

Hz; though the approach is sometimes contraindicated due to concern about induced osteogenic sarcomas);[70] and (3) the still-controversial induced remission of malignant tumors.[71] The Parthian cells may not have been used for any particular one of these purposes: the bone regeneration and tumor regression results cited above involve implanted electrodes—unlikely in first century A.D. Babylon. That the cells generate currents and voltages shown in modern times to be of positive clinical effect tends to confirm the possibility that they could have had a medical purpose in Parthia.[72]

VI. DATE OF THE DEVICE

The object is stratigraphically dated to the first century B.C. to the first century A.D.[73] I am unaware of any attempt to apply thermoluminescence to the clay fabric; ^{14}C dating of the iron may be possible,[74] and X-Ray fluorescence tests of the metals (copper, iron, solder) for characteristic impurities might confirm a dating. Given the suggested medical purposes, it may be possible to narrow the date to the first century A.D.

That the use of papyrus is first attested for Parthia during the same period (Pliny 13.22) might provide a *terminus post quem* were we certain that the devices always involved,

564–74; Carl T. Brighton, ed., *Symposium on Electrically-induced Osteogenesis,* The Orthopedic Clinics of North America 15(1) (Philadelphia, 1984); and Herbert A. Haupt, "Electrical Stimulation of Osteogenesis," *Southern Medical Journal* 77 (1984): 56–64, who notes that the technique goes back to 1812. There are two recent reviews: L. S. Lavine and A. J. Grodzinsky, "Electrical Stimulation of Repair of Bone," *Journal of Bone and Joint Surgery,* ser. A, 69 (1987): 626–30; and A. A. Marino, "Direct Current and Bone Growth," in Marino, *Modern Bioelectricity,* pp. 657–709. Most of the more recent work involves non-invasive electromagnetic current induction.

[70] R. O. Becker, "Electrostimulation and Undetected Malignant Tumors," *Clinical Orthopaedics and Related Research* 161 (1981): 336–39, and R. O. Becker and Gary Selden, *The Body Electric* (New York, 1985), pp. 178, 346. Leroy S. Lavine, M. D. (personal communication, 20 March 1990) expresses doubt about this report (cf. Lavine and Grodzhinsky, "Electrical Stimulation"), as does Moris H. Shamos (personal communication, 30 April 1990).

[71] C. E. Humphrey and E. H. Seal, "Biophysical Approach toward Tumor Regression," *Science* 130 (1959): 388–90; G. S. Williamson and R. Jackson, "Treatment of Basal Cell Carcinoma by Electrodessication and Curettage," *Canadian Medical Association Journal* 86 (1962): 855–62; Clarence D. Cone, Jr., "The Role of the Surface Electrical Transmembrane Potential in Normal and Malignant Mitogenesis," *Annals of the New York Academy of Sciences* 238 (1974): 420–35; M. K. Schauble, M. B. Habal, H. D. Gullick, "Inhibition of Experimental Tumor Growth in Hamsters by Small Direct Currents," *Archives of Pathology and Laboratory Medicine* 101 (1977): 294–97; J. A. Spadero et al., "Antitumor Effects of Silver Electrodes *in vitro*," *Transactions of the Society for Biomaterials* 3 (1977): 149; B. Nordenström, "Preliminary Clinical Trials of Electrophoretic ionization in the Treatment of Malignant Tumours," *IRCS: Medical Science* 6 (1978): 537; M. B. Habal, "Effect of Applied dc Currents on Experimental Tumor Growth in Rats," *Journal of Biomedical Materials Research* 14 (1980): 789–801; B. Nordenström, *Biologically Closed Electrical Circuits* (Stockholm, 1983), pp. 1–11, 318–38; S. L. David et al., "Effect of Low Level Direct Current on *in Vivo* Tumor Growth in Hamsters," *Cancer Research* 45 (1985): 5625–31; and M. Yokoyama et al., [The Use of direct current in the local destruction of cancer tissues], *Gan to Kagaku Ryoho* 16 (1989): 1412–17 [Japanese].

[72] I have benefited from correspondence with Robert O. Becker M.D. (who indicates, personal communication, 5 February 1990, that "[p]resent knowledge indicates that clinical applications of the artifacts could have included pain relief, . . . healing, and . . . treatment of local infections"); Z. B. Friedenberg, M.D. (who indicates, personal communication, 16 February 1990, that "[f]or any effect to be observed it would be necessary for the [electrodes] to be in contact with the [body] for a long period . . . more than several weeks . . . the voltage would have to be [about] ½ volt . . . the current between 5 μA and 20 μA"); and Leroy S. Lavine, M.D. (who indicates, personal communication, 20 March 1990, that "[l]ow intensity direct current for stimulation of bone healing is still being used . . . ").

[73] Al-Haik, "Galvanic Cell," p. 103.

[74] For the method, see Nikolaas J. van der Merwe, *The Carbon-14 Dating of Iron* (Chicago and New York, 1969), pp. 69–86; experimental results (pp. 87–107) are quite good back to the fifth century B.C. at least (no older samples checked).

as the Seleucian and Ctesiphontine models seem to involve the use of papyrus. That the distillation of vinegar followed that of alcohol is likely, and that the distillation of alcohol is first attested in late first century B.C. might provide nearly the same *terminus* were we certain that the electrolyte was distilled vinegar. That Seleucia shows greater Oriental influence after A.D. 43 might provide a similar *terminus* were we certain that a necessary stimulus came along the Silk Road from the East.

More reliable than these is the fact that the use of living electric fish as an analgesic is first attested during the first century A.D., and any medical application of this device must be later.[75] Hence, the passages cited provide a *terminus post quem*.

VII. CONCLUSION

The Parthian galvanic cells seem to have parallels (though crucial details differ) in the Sasanian period and could not have been used for electroplating. This re-opens the question of their application. Various details of the device, the ancient context, and modern medical practice combine to make it possible and even likely that the cells were used as a local electrical analgesic. The inventor was likely a Parthian *asû,* and the devices were associated with magicians and so never entered Greco-Roman science.

Seeing these electric batteries, we are struck by the foregone opportunities, but in their context, they were merely one not necessarily very effective tool of practical, magic-using physicians on the edges of the Greco-Roman world. In such a context, opportunities such as electroplating did not exist (to say nothing of electric heat, telegraphy, electromagnets, and electric lights). I would prefer to view the devices in light of the ancient outlook and seek an explanation therein (whether as substitute ichthyoelectroanalgesia or otherwise). It is probable that the device later became merely a conjurors' trick and gradually faded from view, just as the magicians of Mesopotamia did.

[75] Scribonius Largus *Compositiones* 11 and 162.