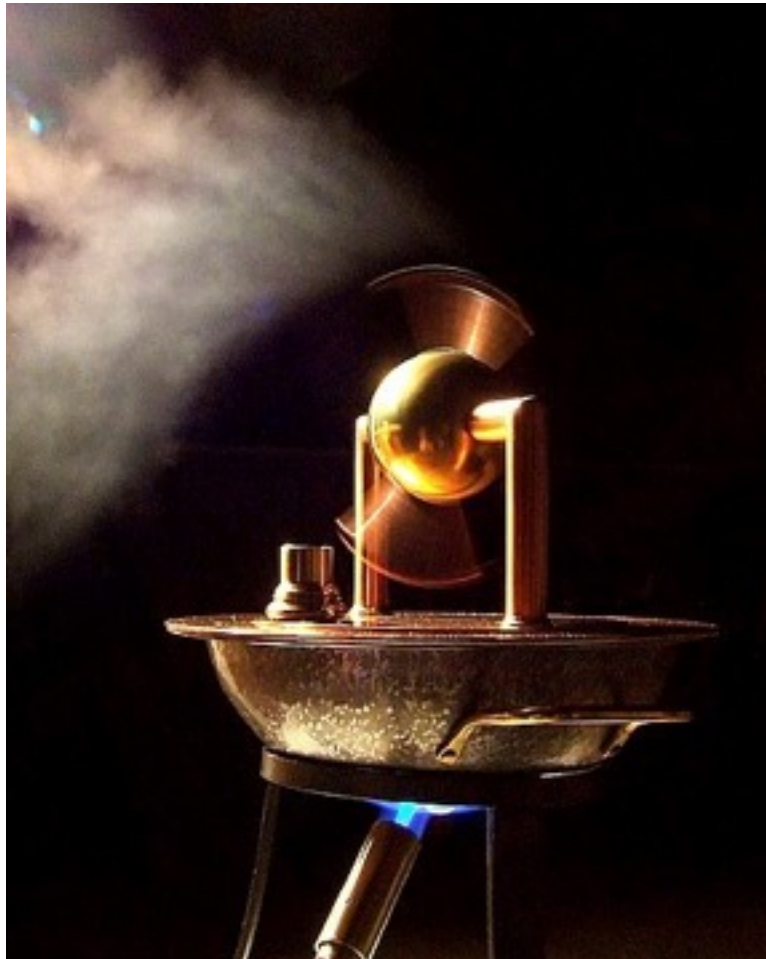


Ancient Greek Gadgets: Toys or Tools?

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Introduction

How can one answer a question which relies on evidence, when there is little to no physical evidence left? This was one of many questions I began asking myself as I started to research this topic in detail, and realised that almost every primary source I encountered was literary, and concerned hypothetical gadgets that may never have seen the light of day. I wanted to examine the purpose and use of such objects; what if they were never used at all?

I can only theorise as to the fate of many such inventions, and attempt to present fairly what few genuine gadgets remain, without corrupting deductions from a lack of comparative evidence. As it stands, literary sources are thankfully not so thin on the ground, although the original manuscripts themselves and modern translations are often unreliable. Consequently ancient technology is a difficult topic to grasp, and I will dedicate part of this introduction to a summary of the subject and the evidence surrounding it, in order to facilitate understanding of the following chapters.

As for my dissertation title itself, I was fascinated by the machines I was reading about, and could not help but wonder at the absurdity of some – a steam machine that merely causes a triton to whistle and a bird to revolve? A coin operated slot machine that dispenses a small handful of holy water? Or most intriguing (and probably well known) of all, a complex geared mechanism that could predict the movement of the stars, the moon, and even inform users of dates of the olympic games, yet left virtually no impression upon mechanical history?

The evaluation of such contrary machines was my aim via a radically simplified title, which I thought summed up the sentiment in a manner which although crude, I thought quite catchy: Were these “tools” in the modern sense of gadgetry, comparable to tablets, clocks or toasters, or were

these merely the playthings of over enthusiastic classical scholars?

This dissertation is split into three chapters, which each cover possible purposes for these machines. I have identified these as research, entertainment, and religion. I will not be covering warcraft as I believe these objects are less easily described as gadgets, and furthermore fall rather easily into the “tools” category – the catapult for example, was not an item to be played with.

Ancient technology and evidence

The concept of technology goes back a long way. The first mention of complex machinery comes with Homer's Iliad, and the moving golden tripods of Hephaestus¹. These machines however are objects of mystery, and their function is not fully explained to the reader. Homer describes their general form and mentions wheels being fixed to the base, but then describes their self-movement as a seemingly magical feat, a product of the craftsman god's ingenuity. Indeed, they are referred to as “αὐτόματοι”, machines that move of their own freewill, “a wonder to behold”². Thus can we see the Greeks early on were fascinated by strange and seemingly inexplicable devices. Literary evidence of the Greeks genuinely building machines however only starts to crop up around the beginning of the 4th century BC. The *Mechanical Problems*, tentatively attributed to Aristotle, deals with mechanical theory. Ctesibius, an author cited by many ancient scholars as the specialist in the area, produced several works in around 300 to 270 BC, although unfortunately none of them remain³. Archimedes met with a similar fate, and only his theoretical works survive; he is however

¹ Iliad.18.370-380

² “θαυμα ιδεσθαι”, as translated by Murray in the 1924 Harvard University Press edition.

³ Zurcher.2004.55

accredited with numerous inventions, such as the endless screw and the compound pulley⁴. Not including works on war machinery, literary evidence beyond this point begins to thin, with Vitruvius and Heron of Alexandria providing a final burst of ingenuity before classical machinery grinds to a halt. (Biton provides six chapters dedicated to an unspecified Attalus, but scholars universally agree his descriptions are incomprehensible, and there are no translations from the original Greek⁵).

I have furthermore chosen to focus on Greek technology rather than Roman. While these are of course interlinked, their attitudes towards machinery differ, and literary sources reflect this contrast of interests. The Romans tended to be more practical when it came to technology, presumably as a result of such devices being commonplace – it must have been difficult to be impressed by unusual machines when aqueducts, bathing complexes and roads were an intrinsic part of everyday life. Brumbaugh rather amusingly sums up this opinion via a stereotypical Roman question: “Can it crush gravel, and if not, can we bathe in it?”⁶. Vitruvius reflects this trend, with his work *De Architectura* focusing on building, besieging and measuring machines, while completely ignoring automata. Plutarch even goes as far as to dismiss military siege engines altogether, claiming they were far too easily bogged down⁷.

Granted, Greek attitudes were not always the most enthusiastic either. Archimedes in a letter to Eratosthenes admits that “certain things first became clear to me by a mechanical method”, but then immediately puts his faith in geometry instead, arguing that an “investigation by the said method

⁴ Drachmann.1963.10

⁵ Drachmann.1963.11

⁶ Brumbaugh.1966.94

⁷ Plutarch *Life of Marcellus* 15

did not furnish an actual demonstration”⁸. Technology appears to have been considered an inferior art to the purer sciences, which Landels describes as an “anti-physical trend”, originating from Plato's contempt of the physical sciences over philosophy⁹. However, the development of scientific schools in cultural hubs such as Alexandria or Rhodes seems to have boosted mechanical knowledge. Heron of Alexandria is the result of this sudden interest, providing several detailed works on fascinating yet odd machines. His dates are uncertain; not only are there multiple Herons from the relevant centuries, but his works also give few clues as to the context he was working in. His *Dioptra*, a book on the famed measuring device, gives the closest estimate, as it mentions a lunar eclipse Neugebauer calculated could only refer to an occurrence in 62 AD¹⁰. Most scholars accept this date, bar a few exceptions¹¹. Despite belonging to a later period, Heron's works clearly compile centuries of research, demonstrating techniques originating from Ctesibius, making him a valuable source for classical engineering. Furthermore, these techniques have been combined in ways that suggests he too, and his peers, were experimenting with technology.

His *Pneumatics*, a compilation of machines and my primary source of evidence for this dissertation, covers relatively modern techniques, from wind and steam power, to gears and cogs. It bypasses traditional classical rules with an unusual literary structure for the time. Consisting of lists and explanations of various machines, it seems closer to a dictionary of marvels than a serious literary work (especially strange considering Heron apparently wrote other more conventional works, such as the *Mechanics*, a treatise on science and mechanisms). Brumbaugh even considers Heron meant

⁸ Archimedes, *On Method* in Heiberg.1897.13

⁹ Landels.1978.187

¹⁰ Drachmann.1963.12

¹¹ Landels.1978.201, Drachmann.1963.12; although Brumbaugh believes he lived in the 2nd century AD, despite writing thirty years after Neugebauer's research was published.

it as a novelty, combining all and any devices he found interesting into a single book¹². It is crucial for this dissertation since many of the advanced gadgets it describes are never referred to elsewhere. Why on earth would such ground breaking inventions (their worth proven in modernity, such as steam powered engines in the industrial revolution) have been overlooked by antiquity? It implies their value was not understood, or was ineffectively used. Heron himself alludes to the superfluous nature of his machines in the introduction, referring to some as “useful everyday applications” and conceding less impressively to others that they produce “remarkable effects”¹³. It is the balance between the two that will be examined in this dissertation. Aside from literary references to extant machines, very little else remains. I will of course refer to the Antikythera mechanism, although this is a device that has already been thoroughly explored¹⁴. Beyond Greek remains, there is an abundance of Roman evidence, such as the tower of the winds in the Athenian agora, and archaeological finds that stand as evidence of their ability to harness water power. Despite these limitations, the variety and peculiarity of the machines described still compels a debate of their purpose, and the role they played in the classical mindset.

¹² Brumbaugh.1966.98

¹³ Landels.1978.29. Woodcroft's version is more elaborate, and translates is as “some of which produce the most pressing wants of human life, while others produce amazement and alarm”.

¹⁴ De Solla Price was the first to write a full article on the mechanism in 1974; there have since been multiple corrections to his work, including reconstructions and a research project.

Chapter 1: Research

Machines that were invented to demonstrate research are particularly interesting, since their purpose is twofold. Are these to be seen as tools, used to increase knowledge of techniques and pass them on to students, or as toys, since the scholars were experimenting purely to impress their patrons? Heron mentions a number of strange machines that fall under these categories. It is important to mention first of all that the *Pneumatics* has solely been translated into French and English, and copies are scarce. I have used a combination of the two, for Woodcroft's English language edition dates back to 1851, and can be overly elaborate. By comparison, Argoud and Guillaumin's French translation is more recent, having been published in 1997, and their reconstructions are more accurate. I have included reconstructions from both in the bibliography to give a clear view of their differences of opinion. There is also not enough space to cover all of Heron's fascinating machines, so I have chosen a few that underline the problem well: an orb that presents incredible physics to introduce the topic, and steam powered machines to illustrate the contrary nature of Greek research.

Alexandrian influence and the *Pneumatic's* stranger devices

A good machine to start with is Heron's "earth suspended in the heavens", an odd contraption that features in his *Pneumatics*. The device falls into the "remarkable effects" category, for Heron gives no reason for its existence, other than the accomplishment of the proposed effect¹⁵. His description, a small paragraph, is fairly short in comparison to others, and missing a component (the siphon

¹⁵ Machine 46: Translation by Woodcroft.1851.69, Argoud.1997.136; fig 1, 2, 3 and 4

necessary for removing water is not included in Heron's text). Either the translation has been corrupted over the centuries, or Heron did not fully understand the machine he was describing¹⁶. It consists of a glass sphere, split into two sections by a flat bronze disc. At the centre of this disc is a circular hole, just slightly larger than a ball. Heron then prescribes filling the lower section with water, and then inserting the ball into the hole. Due to the water, the ball floats. What Heron found incredible however, is the fact that when the water is removed (presumably via the exit of a non-existent siphon), the ball stays in place, rather than falling as it should. The scientific reasons for this are fairly complex, and involve a combination of bottom chamber compression, surface friction and a "leakage of air into and out of the bottom hemisphere"¹⁷. It is understandable Alexandrian scholars were flummoxed, as their knowledge of siphons and pressure merely extended to the creation of vacuums, and movements of air¹⁸: a suspended object must have seemed nigh on miraculous.

Since Heron gives a description of the device with no context or effort to explain the effect, readers can only assume this is a product of experimentation. It falls perfectly into this category, for not only is it proof of scientific research into unknown physics, but it can also be supposed Heron included it as a lesson to his readers (perhaps his students, if not patrons) on the inability to explain certain aspects of science. Whether he did in fact have a contemporary explanation however, is debatable. The fact that Heron says nothing of its origins is telling. Surely, had this been his own research, he would have found it worth more than a few lines? Brumbaugh proposes an interesting dilemma: that it may have had origins in a "Stoic pneuma laboratory"¹⁹. Heron usually describes the

¹⁶ Brumbaugh.1966.85

¹⁷ Brumbaugh.1966.107

¹⁸ *Pneumatics* introduction on the siphon and the vacuum.

¹⁹ Brumbaugh.1966.107

workings in detail, but here he gives nothing away, and modern scholars have been left to speculate as to its provenance. So either there was truly no explanation available, or Heron disagreed with the proposed theory. This would make sense if it was a Stoic proof, since Heron was an Epicurean, going by the model of the universe given in the introduction²⁰. The effect of the device could be misconstrued as proof that air was a physical matter, capable of supporting the ball within the glass sphere. Stoic physics of course focuses on *pneuma* as the insubstantial matter that supports the universe. Furthermore, the Stoic school of Alexandria was actively trying to prove the existence of their mythical “breath” of life through the science of medicine – according to Galen, Erasistratus attributed the bluish colouration of veins to *pneuma*²¹. If the Stoics were using medicine to illustrate their models, why not machines as well?

One could argue such efforts may have gone out of fashion by Heron’s time. Yet it is unlikely such ideas would have declined after the Hellenistic period, since despite Ptolemy VIII's banishment of scholars from Alexandria in 145 BC²², the Romans too were incredibly supportive of intellectual activity. Suetonius mentions that Claudius, of a similar period to Heron, paid for the refurbishment of the library building²³. Furthermore, the Roman government during the imperial period took responsibility for stipends and meals paid to the scholars, and also gave them tax exemptions²⁴: such privileges would have preserved the schools of classical thought, rather than wiped them out.

If the orb was indeed used for such a purpose, it could be an example of such devices and machines

²⁰ In his introduction to the *Pneumatics* he makes reference to “particles” that form air, fire and other elements, comparing them to grains of sand. This is similar of course to the atoms of Epicurean physics. Brumbaugh.1966.106 refers to him outright as such, as do James and Thorpe.1995.114.

²¹ Von Staden.1989.260

²² Athenaeus *Deipnosophistae* 4.83.184b-c “for he ... exiled ... philologists, philosophers, mathematicians, musicians, physical educators, as well as physicians and many other professionals” (Von Staden.1989.68)

²³ Suetonius *Claudius* 42; The emperor ruled in from 41 to 54 AD, a mere few decades before the proposed time period for Heron.

²⁴ Watts.2006.147; Fraser.1972.316-7

being used and experimented with to prove views of the universe, much as modern scientists do today (most notably the Hadron Collider and its revelations on the nature of atoms). Of course, this is purely hypothetical. Any genuine evidence that relates to the use of research is tantalisingly vague. Celsus justifies dissection by stating it was necessary for students, and the vivisection of prisoners by claiming that cures for the innocent could be found from deaths of the guilty²⁵. Dissection was as avant-garde in its own sector as Heron's steam machine was in his *Pneumatics*, perhaps even more so, as it was a phenomenon geographically and temporally restricted to Alexandria in the Hellenistic period²⁶. Celsus also dates to around the early first century AD, which is relevant since his views were probably influenced by the opinions at the time. If the idea of science as a tool for future benefit, rather than just the fun of experimentation existed for medicine in the first century, then why not for engineering too? It is a fascinating conundrum to debate. Thus can be introduced the difficulties and guesswork involved in understanding the use of such devices.

Power Sources and the elusive steam engine

The earth suspended in the heavens is not the only intriguing machine Heron describes, nor the only one that casts the reader into uncertainty. The several steam powered machines in the *Pneumatics* are also cause for confusion, for while Heron similarly gives no explanation as to their purpose, he also fails dramatically to acknowledge their potential. This is in fact odd, since energy sources (while primarily restricted to man and animal power) were in perpetual development in antiquity. Hydropower was in common use by the first century AD, although far better harnessed by Roman

²⁵ Celsus *de med.* 74 (Von Staden.1989.145); *de med.* 23-26 (Von Staden.1989.187)

²⁶ Vivisection was also restricted to this period, but is never referred to by Galen, casting uncertainty over its existence.

engineers than Greek²⁷. Lucretius, writing during the first century BC, compares the movement of the heavens to “rivers turning wheels and buckets”²⁸. It implies the Romans were using water wheels as early as the Republic, although there is little evidence they were used for anything more than milling²⁹. Ctesibius, the third century BC mechanic who benefitted from the height of Alexandrian patronage, allegedly built a water pump³⁰ - Zurcher also mentions the same type of machine was found in Silchester, England, as well as in Castranovo, Italy. Sadly even Greek water powered inventions were better used by the Romans, if the latter spread this model around the mediterranean. Yet the Romans do not seem to have experimented with other types of energy, and beyond hydropower, use of the natural elements becomes restricted to a few instances in Heron. Wind power is mentioned once, in a curiously complex machine that merely blows an organ; even Landels refers to it as a “toy”³¹.

Steam power, despite its modern significance, is equally under appreciated. There are only an underwhelming four machines in Heron's entire compilation that make use of steam. Furthermore, none of the devices have any practical purpose, but seem rather to be displays of effects, with the machines becoming increasingly ridiculous in progression. The first, machine 45, comprises a cauldron producing steam, which is then funnelled through a narrow tube pointing up³². The resulting powerful jet of steam is capable of holding a sphere suspended in the air, although one can

²⁷ Landels.1978.17

²⁸ Lucretius *On the nature of the universe* V 515-6

²⁹ Landels refers to a passage in Ausonius from around 40 AD, which suggests water wheels were used to power saws to cut through stone. There is no physical evidence this ever occurred, however.

³⁰ Zurcher.2004.55

³¹ Machine 77: Translation Woodcroft.1851.108, Argoud.1997.126; Reconstructions fig 5, 6 and 7; Landels.1978.27

³² Machine 45: Woodcroft.1851.68; Argoud.1997.137

be sceptical for how long the ball can stay in place – the entire mechanism seems very volatile³³. It is of little interest when examining steam power, for it does not utilise this as an energy source.

There is no mechanism that harnesses the blast of steam, and it instead serves as an amusing sort of experiment, which one can assume is what Heron intended. Machine 50 is more relevant, although similar to the previous device in that it consists primarily of a cauldron base and a funnel; this tube does not simply open to the air however, but is attached to a circular bronze sphere. The latter has two smaller pipes on opposite sides that extend, then bend at a 45 degrees angle³⁴. When at work, the mechanism is quite impressive, for the steam rises through the central structure and is forced out the bent pipes, propelling the ball into swift rotation³⁵. This is a better example of steam power, as it harnesses the latter to produce speed, although using it for nothing more than creating a spectacle.

The remaining two steam machines in Heron are also relevant, but perplexingly pointless.

Contraptions 74 and 75 are virtually the same machine, comprising a cauldron full of water, and an elevated fire that heats the water from above. The steam then rises and is blasted through a tube in the shape of a serpent, stoking the fire³⁶. The only difference is that 75 has the additions of a triton and a blackbird, which yield trumpeting and chirping noises respectively due to steam being expelled via compressed tubes³⁷. The entire mechanism is focused on self-maintenance, as not only does the snake preserve the fire, but Heron inordinately describes the management and compartments of hot and cold water within the boiler (presumably because the pressure of the steam could be dangerous). The last two additions to machine 75 however are trivial, as while they show

³³ Fig 8 and 9

³⁴ Machine 50: Woodcroft.1851.50; Argoud.1997.140

³⁵ Fig 10, 11, 12 and 13. Fig 14 shows a modern reconstruction in motion.

³⁶ Machine 74: Woodcroft.1851.100, Argoud.1997.174; fig 15 and 16

³⁷ Machine 75: Woodcroft1851.103, Argoud.1997.180 ; fig 17 and 18

how steam can be used to create noise, the same effect could as easily be attained with a normal pipe. Moreover, the choice of ornate animal forms implies the scholars were treating these devices as toys. All the steam machines in Heron seem to fall victim to this, as while the first couple are austere in design and effect, they do not achieve any practical purpose. They are instead clever displays of the inventor's knowledge, the products of experimentation with steam. While it is impossible to pinpoint a time period for these inventions (Heron could be sharing inherited knowledge) the variety of their forms suggests a significant amount of work was put into manipulation of the elements. This seems sadly though to have been research for the sake of amusement. It is confusing to think that Heron or his peers never saw the possibilities of such devices, when in the first century AD the Romans were pushing hydropower to new extents. Heron in fact describes all the components of the modern steam engine through various machines³⁸: force pumps are used in machine 42, in which air is forced into a reservoir³⁹; valve mechanisms appear in Heron's fountain, where liquid is expelled via compressed air⁴⁰, comparable to insecticide spray⁴¹. Yet nowhere does Heron combine these, nor are there any references to this ever happening. When the research and techniques were clearly there, why did steam power remain a toy despite its overwhelming potential?

Without presenting economic and social arguments over a classical “industrial revolution”, the technical reasons are simple: none of these steam machines were the least bit practical. Heron's contraptions were clunky and inefficient, incapable of producing or harnessing enough power to be of use. Take machine 50 for example, the device that uses steam to rotate a bronze orb. The shape of

³⁸ Landels.1978.30

³⁹ Machine 42: Translation Woodcroft.1851.65, Argoud.1997.132; Reconstructions fig 19 and 20

⁴⁰ Machines 9 and 10: Translation Woodcroft.1851.23-5, Argoud.1997.64-8; Reconstructions fig 21, 22, 23 and 24

⁴¹ Landels.1978.30

the device would surely have obstructed its own function, since for the ball to rotate effectively, it would require distance from the pipes. In Heron's description however (and subsequent modern reconstructions) it is hindered by friction⁴². Increasing the space between the pipes and the bronze sphere would also be counterproductive, as it allows steam to escape from the gap. More than just the design is flawed, for its power output is also very low. Machine 50 can only produce 25000 BTU per hour, in other words one tenth horsepower⁴³. Although calculations vary, one horsepower is approximately equal to the efforts of four men⁴⁴. To give a better idea of modern standards of energy, Landels states one gallon of petrol produces nine horsepower, equivalent to three dozen men⁴⁵. Whatever the figures, the fact remains that Heron's steam machine was not at all effective, discounting the labour needed to transport fuel if one was to enlarge the device.

The gadgets in Heron are curious, for while they have clearly been well researched, the author gives no indication this experimentation led to anything more. The absence of evidence also points to this. What was the reason for such experiments, if not to advance technology? In terms of research, technology is most emphatically a toy, an amusement for the scholars who invented these machines, and an enjoyable curio for their patrons. This is a common theme with machines in Heron, as will be examined in the next chapter.

⁴² Landels.1978.29

⁴³ Landels.1978.29

⁴⁴ One horsepower is equal to 550 ft-lb/sec, according to the CGPM. Assuming an average man weighs 180 pounds, and can climb a ten foot set of stairs in around 15 seconds (a rate he can easily maintain). He is thus lifting 180 pounds at a rate of 0.7ft/sec ($10/15 = 0.66$), thus producing 120ft-lb/sec (0.66×180), equal to just under $\frac{1}{4}$ horsepower.

⁴⁵ Landels.1978.29 although Landels is more conservative, considering one horsepower to be equal to ten men, therefore 90 men to a gallon of petrol.

Chapter 2: Entertainment

So if practical machines such as steam power, or research oriented machines such as the earth suspended in the heavens were merely amusements, what else could potentially have been of actual use to the ancient Greeks? Having examined the other machines in the *Pneumatics*, a major theme seems to be entertainment. By definition, these could be classified as toys. It is therefore more interesting to examine these machines from a different point of view: Were these machines ever used in an everyday context? If so, despite their function as an object of entertainment, they were fundamentally useful. If not, and these appear to be purely hypothetical inventions (of little use similar to the research oriented gadgets in the previous chapter) then they can be more comfortably classed as toys. I will thus examine both Heron's collection of entertainment devices, and a few real machines that have survived the ravages of time.

The *Pneumatics*: A drinking catalogue?

One of the most unusual things about the *Pneumatics* is apparent from the onset of the table of contents. Almost every other machine appears to be a novelty drinking vessel, involving the manipulation and distribution of water and wine. I amassed a list of every device I believed followed this stereotype, which is included in the bibliography⁴⁶. According to this criteria, 30 out of 78 machines in Heron are drinking vessels of some form, over a third of the entire book. The steam machines are surrounded on all sides and severely outnumbered by wine distributors – it makes one wonder whether this is indicative of a skewed thematic approach to machinery at the

⁴⁶ Fig 1 list of drinking vessels. Of course, this was compiled from my own opinion of what comprises a novelty sympotic drinking vessel – I have included the list to allow the reader to make their own deductions.

time, or of Heron's personal interests. What is more perplexing is the fact that many of these devices produce the same effects, and some are even given the same name. Machines 59 and 65 are both entitled “A Vessel from which wine or water may be made to flow separately or mixed”, while the intermediate machine 64 is a drinking horn which can produce either pure or mixed water and wine. What was the point of including so many identical devices? Even the inner workings are fairly uniform. Machine 8, a “Vessel for discharging liquids of varying proportions” similarly expels water or wine through the management of air pressure. It consists of a jug with a top and bottom partition, separated by a bronze disk in which a couple of small holes are drilled. A siphon starts open in the bottom compartment, and travels up the vessel, through the bronze disk, to join with the handle in the upper partition. Unbeknownst to the viewer, the handle is in fact hollow, and the siphon curves up to the spout, where a small hole allows air to escape from the bottom of the vessel⁴⁷. So normally, when water is poured into the jug, air would escape through the handle, and the liquid would enter the lower compartment through the bronze holes drilled in the disk. However, an interesting effect is produced when one blocks the hole on the spout, for the air is then compressed and unable to escape. So if one pours water first, then blocks the hole and pours in wine, the two liquids would not mix.

This sort of technique is used in almost every drinking vessel in the *Pneumatics*, with the aforementioned machines 59, 64 and 65 adapting the same procedures to a slightly different formula⁴⁸. One can presume the sheer variety of these contraptions indicates technology was most commonly used for entertainment, and more precisely, in a context of festivities. It would make sense that patrons would appreciate this most, for as Wikander argues, this focus on “miracle”

⁴⁷ Machine 8: Woodcroft.1851.22, Argoud.1997.62 ; fig 2 and 3

⁴⁸ Fig 4, 5, 6 respectively.

machines with the mechanism hidden from sight might be because patrons found this more entertaining than bald research, a far less dramatic medium⁴⁹. One could argue patrons even found this more useful – what better way to impress one's peers, than to display their educated status with complex, hidden machinery? Such behaviour brings to mind the Greek symposia, as novelty machines would fit in well with the stereotype of culture and revelry. While it is difficult to pinpoint the use of Heron's drinking vessels to these events, trickery of the mind was certainly a popular sympotic theme, and similar practises may have been propagated by Alexandria's Greek roots. Odd and interesting drinking vessels were abundant, judging from the remaining pottery. Kylix with unexpected images at the centre, such as a demure woman rather than the usual erotic scene must have been a source of amusement, as they allowed the drunken reveller to finish his wine, then presumably reminded him of more serious subjects, such as his wife. Another common theme on this type of cup is a set of eyes painted on the side, widened and styled with concentric circles that give them a slightly mad appearance⁵⁰. As the individual lifts the kylix to drink, the eyes would be in position of his own, making him seem inebriated. Such trickery is mirrored in Heron, who even treats the devices himself as a game, saying of machine 8 that it can pour wine for some, “or if we want to play a joke on somebody, water”⁵¹.

The Ptolemies were insistent supporters of medicine and other arts in Alexandria, even going as far as to allegedly supply Herophilus and Erasistratus with live prisoners for vivisection⁵²: if they were willing to take extremes for the sake of research, then it would not be a huge step to assume they

⁴⁹ Wikander.2008.790

⁵⁰ Fig 7

⁵¹ Landels.1978.202 translation. Woodcroft is more elaborate and wordy, translating it as: “so as to pour wine for some, wine and water for others, and mere water for those whom we wish to jest with”

⁵² Celsus *de med.*23 translated by Von Staden.1989.52

funded the development of machines as entertainment for their own festivities. The Romans were certainly not shy of such acts, as the late 4th century AD Lycurgus cup shows they were experimenting with nanotechnology, and typically putting it on show rather than anything more useful. The glass is a mix of gold and silver, so finely ground that the particles are thinner than a grain of sand. The resulting mix has the glass appear green in normal lighting, and red when a light is shone behind (or certain liquids are poured in)⁵³. Amusingly, the Romans carved a satyr onto the glass so it appears benign under normal circumstances, yet when the effects of the glass are played with, it seems red and demonic⁵⁴. One can imagine a rich Roman patron pulling it out as a party trick. While it is likely Heron had entertainment in mind when compiling his list of machines (this was probably not only a factor for drinking vessels, but for other contraptions too, as displayed in chapter one on the form of Heron's steam machines) it is hard to justify the argument that machinery in antiquity was considered a plaything, unless one examines the remaining physical evidence as well. As previously stated, very little remains that can be classified as classical technology, as most evidence lies in the texts. The Antikythera mechanism is by far the most famous, and is also the most advanced machine attributed the Greeks, surpassing anything Heron describes. It would be an oversight to pass it over, although bibliography surrounding the device is already extensive. I thought it would therefore be interesting to examine the mechanism's potential for entertainment, and whether it was actually used for such purposes, an area which has not been heavily documented.

⁵³ http://www.britishmuseum.org/explore/highlights/highlight_objects/pe_mla/t/the_lycurgus_cup.aspx

⁵⁴ Fig 8, fig 9

The Ancient Analog Computer

The Antikythera mechanism, named after the island next to the shipwreck, is by far more complex than anything Heron, or any other literary source for that matter, has to offer. Only two machines in the *Pneumatics* use gears, and both are relatively simplistic. The Antikythera mechanism however consists of over thirty gears, a sophisticated analog computer, only reinvented a thousand years later with the first European clocks. It has been approximately dated to the first century BC, a little earlier than Heron, as Price mentions the lettering is “characteristic” of this period⁵⁵. It is odd that such complex research had not influenced Heron's compilation. The only explanation for this strange absence would perhaps be the machine's complexity – Heron may have not understood or had access to such a device, and therefore did not include it. His descriptions are all indeed remarkably short, and it would have been impossible to explain the monstrous device in the space of a page or less. It could very well have reached Alexandria however, as similar machines are mentioned in Latin texts. Cicero describes such a contraption in Rome⁵⁶. It is likely that if the Romans inherited Greek research, then the techniques themselves would have been pioneered and propagated in the Greek scholarly hubs. Zurcher certainly considers the mechanism may have been developed in Alexandria, although he dismisses the possibility in favour of Rhodes, due to the presence of Hipparchus and the school of astronomy on the island⁵⁷. It is described as a clock since it exhibits the movement of the sun and the moon, as well as eclipses and various other astronomical positions⁵⁸. The device is in fact closer to an astrolabe, of the type reportedly invented

⁵⁵ Price mentions professor Benjamin Meritt's research, which points out that the left vertical of II is larger than the right, typical of Augustan period epigraphy. Price.1974.48

⁵⁶ Cic. *De re pub.* 1.14.21-22

⁵⁷ Zurcher.2004.84-6

⁵⁸ Price.1974.13

by Archimedes.

At base, as an unadorned piece of machinery, it appears to be an instrument of astrological research, since the internal workings are so intricate⁵⁹. Yet in practise, it seems to have been used differently, and in a more relevant manner for this chapter. Cicero's *De re publica* mentions a similar machine, supposedly invented by Archimedes, which had been looted from Syracuse some centuries earlier. He describes how it was physically unimpressive, but deserved “special admiration”⁶⁰ since “one single turning device could represent uneven and varying movement with totally different rates of speed”⁶¹. Such an effect could only be attained through the use of gears. What is interesting though is the manner in which Cicero came by this device. It was his friend Gaius Sulpicious Gallus that presented it to him, and according to the use of “us”, other members of the same circle. Gallus apparently “began to give a very learned explanation of the device”, and is cited throughout the text as displaying the various workings and history of the machine. It is fascinating that the mechanism was seemingly used as a luxury trinket, to impress the friends of the owner – as apparent through Cicero's use of the word “learned”. He seems to have attributed some of the genius of the device to the Roman inheritor, or at least assumed it has increased the value of their knowledge. Yet the machine was not only used by a variety of owners, but was also built to be understood by any average literate Greek. The main blocks of the mechanism that have survived are very fragile, and only portions of the inscription remain. Enough does, however, to understand these constituted what was effectively an ancient instruction manual. Price has provided images and translations of the writings. The Parapegma inscription had nine lines that are almost legible, which appear to be a list

⁵⁹ Fig 10

⁶⁰ Price.1974.56

⁶¹ Wikander.2007.791

of the movements of different constellations⁶². The back door plate inscription is also mangled, yet the language provides the most direct evidence of instructions: “two pointers, whose ends carry ... four, the one indicates ... the 76 years. 19 years, of the ... so that the whole will be divided ... similar to those on the ... carries”⁶³. Including an inscription implies it was intended to be understood by others rather than just the inventor, and if Cicero describes alternate versions of this device, it creates interesting possibilities.

Were complex clocks of this type invented purely to aid the school of astronomy's research, or were they supposed to be on show? The fact that it was discovered in a shipwreck among other showpieces is indicative of it being a precious commodity, especially when some of the sunken loot is priceless Hellenistic art, such as the bronze Ephebe⁶⁴. This would justify the machine having left no significant mark upon ancient technology, since it was considered a curio rather than a mainstream item. Indeed, Greek clocks were underdeveloped, primarily due to the lack of a decent system to measure time. Water clocks only extended to 24 hours, and furthermore complicated matters by dividing the day into 12 equal hours. The Greeks therefore had a different “hour” period in winter and in summer, since the daylight in winter shortened this to 40 minutes⁶⁵. It is unsurprising Greek scholars constructed an extremely complicated clock. The Romans certainly used more complex technology as showpieces. The Tower of the Winds in the Roman agora of Athens recreated what was probably Ctesibius' design for a water clock, but on an industrial scale⁶⁶. The structure itself is formidably large and well preserved, with an ornate decoration scheme. Each

⁶² Fig 11, 12

⁶³ Fig 13, 14

⁶⁴ Fig 15

⁶⁵ Landels.1978.188

⁶⁶ Noble and Price.1968.350

side of the building was adorned with a sundial, and the personified winds are all carved just below the roof⁶⁷. Considering a triton was supposed to rest atop the roof, the tower would have been a flashy, elaborate structure. The Antikythera mechanism may have been similarly used, but on a smaller scale. Heron's few examples of geared mechanisms, while dramatically more simplistic, are similarly used for leisure purposes: the peg and lever machine which produces a hammering noise, does so to illustrate the sound of a nymph building a ship in Heron's automated theatre⁶⁸.

Most of Heron's machines were aimed at providing entertainment, be it even research oriented machines (the addition of a triton and bird on the steam machine implies the creator decorated it to impress, for a patron perhaps), or trendy drinking vessels. It is rather in the question of whether these machines would ever have physically existed outside the hypothetical, that lies the true answer to this question. According to physical remains such as the Lycurgus cup and the Antikythera mechanism, it is distinctly possible they were indeed made and used for this purpose. They are a rather interesting mash of a toy and a tool, since they provided amusement, but could also be practically used at parties to supply drinks, or bolster the patron's reputation.

⁶⁷ Fig 16

⁶⁸ Brumbaugh.1966.103

Chapter 3: Religion

While Heron's compilation has very few machines that belong in a religious context, the few that do are an odd mix of “miracle” makers, made to fool gullible worshippers, and genuinely useful devices such as taps or slot machines, that replace priestly tasks. He seems to have singled them out for their mechanisms rather than purpose, as his descriptions focus almost entirely on the use of air and pressure over historical use of such machines. As there is no evidence of mechanisms being used in temples, much of this chapter is theoretical. It is interesting however, since Heron's religious machines are probably the most useful devices in the entire collection, compared to curiosities such as the “earth suspended in the heavens”, or the collection of wine distributors. One could imagine many of these actually being put to good use in a temple, had they been properly constructed.

A fraudulent production of “miracles”

Using special effects to inspire awe in unsuspecting devotees was already a common theme in Greek temples, so it is unsurprising machinery seems to have been put to such use. This included anything as innocent as the manipulation of architecture, such as the increased size of the statue of Zeus at Olympia, to create the effect the god would remove the roof should he stand. It also included genuine deceit, such as statues with mouthpieces through which the priests could speak, thereby taking on the voice of a god or spirit and frightening anyone nearby. Machines 17 and 37 in the *Pneumatics* follow the same lines as the latter example, as both aim to trick the target into believing a divine act has taken place. The first, machine 17, sounds a trumpet when temple doors are opened. The model is incredibly complicated for the effect it produces, as it makes use of a

pulley system, and the expulsion of air via a flooding of water into the trumpet. When the door opens, it pulls on a rope, itself connected to a wooden beam further inside the temple. As the beam rises, it ceases to support the trumpet, which is then plunged into a bucket of water, forcing the air trapped within to escape as water enters, sounding the instrument⁶⁹. The machine is so complex that it becomes impractical, and Wikander even doubts it would be possible on a larger scale, which seems likely due to resulting difficulties with the rope in a larger construction⁷⁰. In fact, rather than making the task easier for the temple workers, the effect could probably be more easily attained by a hidden priest⁷¹. Landels amusingly sums up the futility of the device by questioning how the priests would even hide the string and pulley, which would instantly be visible upon opening the door⁷².

Machine 37 is not much better, a contraption which causes temple doors to open of their own accord. The mechanism is once more needlessly complicated, involving an airtight altar, connected by siphon to a sphere partially filled with water. Another siphon connects the sphere to a bucket. When a fire is lit, it heats up the air in the altar, raising the pressure and forcing it into the sphere. The water then goes through the siphon into the bucket, which lowers, tightening the cords and opening the doors. When the fire goes out, the air cools and a vacuum is produced. The air is pulled back in, and a counterweight lifts the bucket, shutting the doors⁷³. The whole process must have been agonisingly slow, as it relies entirely on the boiling and cooling of water in the altar. It would also have been nigh on impossible to time, meaning the machine would have been dramatically

⁶⁹ Machine 17: Woodcroft.1851.33, Argoud.1997.76; fig 1 and 2

⁷⁰ Wikander.2008.789

⁷¹ Brumbaugh.1966.102

⁷² Landels.1978.203

⁷³ Machine 37: Woodcroft.1851.57, Argoud.1997.110; Fig 3 and 4

useless. Amusingly, Brumbaugh even questions the purpose of these devices, wondering of the first whether it was intended as a “burglar alarm”, since it does more to shock the individual than it does to cause divine reverence⁷⁴. While the inventor undoubtedly intended these machines to be fake “miracle” producers, it seems unlikely either of those cited in Heron would have been used in temples⁷⁵. However, even if Heron was inspired by machines he had seen in genuine temples, it stretches the imagination to think that the Greeks would have been gullible enough to believe such contrived “miracles”, especially if they were as blatantly obvious as machines 17 and 37.

It can be argued that divine communication in antiquity was entirely based on such a trusting relationship, and that the Greeks would accept natural or unknowingly fabricated signs as divine intervention. There are inscriptions in the sanctuary of Asclepius at Epidaurus that advertise the miraculous healing performed at the temple, some of which are ridiculous to the modern viewer. One in particular, concerning a Cleo who was apparently pregnant for five years, seems absurd; the inscription becomes quasi-mythical as the account continues to mention that the boy, as soon as he was born, crawled out of the womb and promptly washed himself in the holy fountain next door⁷⁶. There are a whole slew of similar inscriptions from the temple, that seem to have acted as “proofs” of divine presence, intended to draw worshippers in. It is hard to believe anyone with any sense would have believed these tales, and yet numerous similar writings are affixed at this sanctuary, implying this was an effective tradition. They suggest more than just a belief, but a fascination with the inexplicable, and therefore the divine. As any modern spectator would be desperate to understand a magician's tricks, perhaps the Greeks were attempting to emulate what type of

⁷⁴ Brumbaugh.1966.101

⁷⁵ Landels.1978.202

⁷⁶ Inscriptions at the Sanctuary of Asclepius, Epidaurus. Rhodes and Osborne 102, circa 320 BC. Fig 5

miracles they believed the gods capable of, and inspire similar wonder in their peers. While one cannot pin such behaviour on the entirety of classical Greece (Alexandria was far removed and furthermore submerged in Egyptian culture) the machines in the *Pneumatics* seem to imply this tendency. Perhaps Alexandrian inventors liked the idea of technology as an aid to religious propaganda, but were never truly confident enough to take their inventions to the next level. As Landels puts it, “so much for the 'temple miracles' and science in the service of religion and oppression”⁷⁷.

The utilitarian engineer: The coin operated slot machine

Compared to some of the other “miracle” machines, this contraption is in fact fairly mundane: none of the processes are hidden, no belief defying effect is produced – the object simply effects an economic exchange. It probably gains more interest two thousand years after its conception than it did by contemporaries. Yet, it is in the concept itself that the machine impresses. As with other mundane devices in Heron, such as the temple tap, it is not a flashy showpiece, but was instead conceived to aid the priests in their work. The machine resembled a large vase, with an interior encased area holding the device itself, the coins and the holy water. First, a coin is inserted through the slot on top of the machine, which then falls onto an oblong plate. The weight of the money tips the plate downwards. This then lifts the opposite end of the plate, which is attached to a plug at the bottom of the casing. When the plug lifts, water pours out of the case and into the clients' hands. Of course, when the coin eventually falls off the plate, the whole process is reversed, and the water flow ceases⁷⁸. Of most of the machines in Heron, this seems to me to be the most practical, as it is

⁷⁷ Landels.1978.203

⁷⁸ Machine 21: Woodcroft.1851.37, Argoud.1997.82; fig 6 and 7

not simply a theoretical discourse on how one could create supernatural effects, but rather fits into an everyday situation. It improves the efficiency of a mundane exchange, as originally one can assume a priest would have to be at hand to receive the money, and provide the individual with holy water. With this invention however, a priest does not need to be there at all (although it might be unwise to leave the coins unguarded) and instead the religious process becomes entirely autonomous. This is not a process to be shunned, either. While “miracles” certainly create a sense of awe, the act of purification was very important.

An individual polluted by miasma was barred from all corners of a religious life, from sacrifices, rituals and even from entering a temple. While holy water was one of many solutions to this religious “disease”, it was still commonly included in the purification process, as the sacred law of Cyrene shows⁷⁹. While one must be wary of the 4th century BC date and the fact it probably details earlier laws, the information it presents on the act of purification highlights the latter's significance, even on the edges of the Greek world. The list is incredibly varied, progressing from emergency procedures during famine to the economic transactions of wood growing on a sanctuary. The act of “washing” oneself is mentioned multiple times, from instructions related to sex, to accidentally sacrificing the wrong animal. The inscription also illustrates the diversity of situations miasma is caught from, mentioning funerals, and childbirth among other unavoidable things. The jumbled nature of the source makes it unlikely any individual may have spent the time reading it however, as it is extremely long and convoluted. Yet, the laws it describes must have originated from some respected source to have been considered significant enough to re-inscribe – either another older inscription, or word of mouth. If the laws are dependable, then it makes sense that three centuries later when these superstitions are deeply engrained, Heron would wish to improve the process of

⁷⁹ Sacred Law of Cyrene, late 4th century. Rhodes and Osborne 97. Fig 8

washing and purification, since it was an important part of religious life. Unfortunately, there are no practical examples of the slot machine being put into use, and as is the case of many other machines, it is never mentioned outside of Heron's compilation.

It is impossible to know therefore whether this was a handy object in reality, rather than just in theory. Strangely enough, it is the coins themselves that causes scholars to doubt the machine, rather than the concept or mechanism. According to Heron, the user had to insert 5 drachmas for the machine to work. As Brumbaugh points out, this is no small quantity, and he compares it to several day's wages⁸⁰. The only notable comparisons that come to mind are Athenian 5th and 4th century, far from the right period, and location. Aristotle, in his Athenian constitution, mentions that assembly pay for the mid 4th century BC is one drachma, and one and a half for ecclesia kyria⁸¹. Considering the ecclesia lasted half a day, this must have remunerated citizens for at least half a day's work, if not more if the state took into account travel and stay for individuals. However, even this amount was in flux. Aristophanes, half a century before Aristotle, says citizens would fight for the right to stand on the Pnyx for 3 obols, less than half the money it would later become⁸². Still, if a drachma was most of a day's pay for an Athenian in the 4th century, it seems unlikely that inflation would have changed rates so drastically as to alter the average value of the drachma. It is more likely Brumbaugh is accurate in his suggestion, that this is indeed a couple of days pay in Heron's time.

Several day's work for a handful of water can only be classified as a rip-off. Furthermore, the contraption itself does not allow for a large quantity of liquid to trickle out, since the weight of the

⁸⁰ Brumbaugh.1966.100

⁸¹ Aristotle *The Athenian Constitution* 62.2

⁸² Aristophanes *Plutus* 330

coin means the plate will not be lowered for more than a few seconds before it slides off. No reason is given in Heron for five drachmas being the cost for a few drops of holy water, as he only states it in passing. Unfortunately, this implies the quantity was not drawn as an example from an existing, functioning machine. It is more likely he simply drew the number at random as a staple amount, rather than considering the economic plausibility of the cost. So this machine joins the long list of experimental devices that never became mainstream, perhaps built but never properly used for its given purpose. Despite this, the concept of the machine is still entirely utilitarian, which does support the “tool” over “toy” approach. While it could be argued that Heron invented this machine for the fun of putting new concepts into practise rather than out of any practical use, it remains that this is a “labour saving” machine, as Brumbaugh puts it⁸³. Heron may have included the object as an interesting and amusing addition to his list, but the fact remains it was conceived to be useful, rather than simply a toy.

So between fake miracle machines and their labour saving counterparts, none of the religious devices in Heron can be proven to be more than theoretical, and one can even argue they were impractical. It is however their construction that can be criticised, as the concepts themselves are sound. It is unfortunate they were never further developed, since they could have been extremely useful temple tools. While it is just wishful thinking, it is still nice to imagine these type of machines were developed, and Heron was only interested in the mechanisms rather than the more practical aspects of the devices, hence his unrealistic depictions of incredibly useful (and amusing) machines.

⁸³ Brumbaugh.1966.101

Conclusion

This dissertation is aimed at identifying the various purposes and contexts of Heron's machines in the *Pneumatics*. This also led to examining another conundrum: whether some machines were displays of theoretical knowledge, via a machine with a superficial title and aim, rather than genuine devices that served to simplify or enhance an individuals' tasks, as modern machines do. In terms of research oriented machines, the devices examined fall into the first category, since they appear to be fun experiments on the part of the engineers. They had little effect upon technology at the time, despite their potential – steam power was not used again arguably until the 19th century. As such, it is hard to classify them as tools, since they served no purpose other than to amuse their makers, and perhaps impress patrons with inexplicable effects (such as the suspended sphere in machine 46).

On the other hand, machines invented purely for the sake of entertainment appear to have been put to better use. The *Pneumatics* presents vessels drinking horns that could easily have provided a spectacle at festivities, and are similar in some ways to the sympotic kylix. Even contraptions as sophisticated as the Antikythera mechanism seem to have been appreciated for their complexity, although onlookers felt no need to understand the workings and improve upon them. In fact, they seem to assume they were invented by a superior intellect, as Cicero elevates Archimedes onto a pedestal he implies none could ever reach. So while in practise they were probably better used than their purely technical counterparts, they were still effectively treated as luxurious toys. Finally, even Heron's religious machines, under scrutiny, were far too impractical to be of any use. For the last case it is particularly strange, since other than war related machinery, this context is the most likely

to have benefitted from the technology described by Heron. Simplifying temple processes such as the distribution of holy water could easily have been attained, with a slightly better developed slot machine than the one Heron describes, while fake miracle machines would surely have provided (granted heretical) entertainment.

One can only conclude that Heron did not have practicality in mind upon compiling the *Pneumatics*, but rather was fascinated by the variety of techniques he encountered. Considering his collection is our best evidence of classical technology, it is telling that most of his machines seem to be passing amusements. While the Romans and Greeks may have used simple machines such as fountains and baths, no effort was made to increase the use of machinery in their daily lives. This disregard was so immense that even upon discovery of the Antikythera mechanism, there were doubts such an elaborate array of gears could be attributed to the Greeks, since literary evidence presents nothing that advanced⁸⁴. Technology was instead treated as a fun, but unnecessary hobby. This is reflected in technological history itself, since most of classical engineering techniques were forgotten for centuries, and restricted to geographical hubs such as the schools in Rhodes and Alexandria. As a result, it is more logical to classify ancient gadgets as toys rather than tools.

While my dissertation has primarily relied upon two translations of Heron, this has also hindered efforts, since one version was written over a century ago and is therefore stylistically outdated. The other is more recent, but is the sole French translation of the *Pneumatics*. A new English translation of Heron is required, but none yet have undertaken the task, a shame considering how important, yet unappreciated his works are. For some of his other books, such as the *Dioptra*, there is

⁸⁴ Price.1974.10. Apparently soon after the mechanism's discovery, some scholars were unwilling to believe the Greeks were capable of anything so intricate, and proposed instead that it was the debris of a later shipwreck.

unfortunately no English translation. While it was possible to write a discussion on the nature of ancient machines from the literature available, it is still relevant to note the task would have been simpler with a wider variety of sources, both primary and secondary.

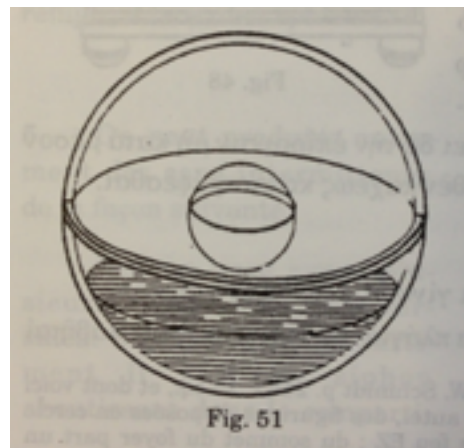
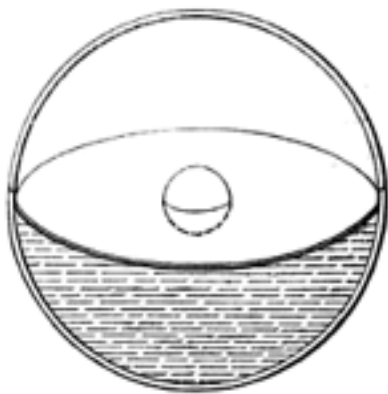
List of Images

As there are a large number of images, I have restarted the numbering from one for each chapter, to make the process easier to follow. There are 48 pictures in total. I have also placed many side by side, since some are practically identical reconstructions, and it makes it easier to compare them. If I am citing images of Heron's machines, the number and name of the machine will be stated before the various models.

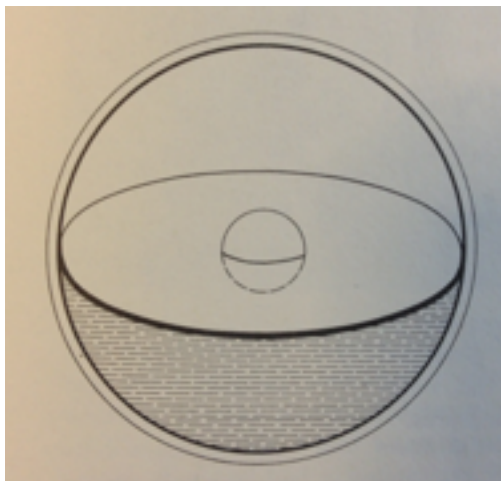
Chapter 1: Research

Machine 46: The World represented in the Centre of the Universe

Figures 1 and 2: Images from Woodcroft.1851.68, Argoud.1997.136. Both reconstructions are almost identical, and both display Heron's technical mistakes, as they are missing a siphon through which one can remove the water. They are also missing any kind of support for the glass globe.



Figures 3 and 4: Images from Brumbaugh.1966.85. His model is so similar to Woodcroft's it may well have been inspired by the latter. What is interesting is his physical reconstruction: He was able to make the device work, but his globe is not circular, and he had to include a siphon to remove the water. As can be seen in the photo, the ball is held in suspension despite the lowered water level.



Machine 77: The wind powered organ

Figures 5 and 6: Courtesy of Woodcroft.1851.108 and Argoud.1997.126. I have placed these together since they are both quite complex and ornate reconstructions, and are more difficult to understand. The mechanism itself relies on wind to turn the vane, which then manipulated compressed air in order to sound the organ. It is amusing our first evidence of a windmill has it serving no greater purpose than to work a musical instrument.

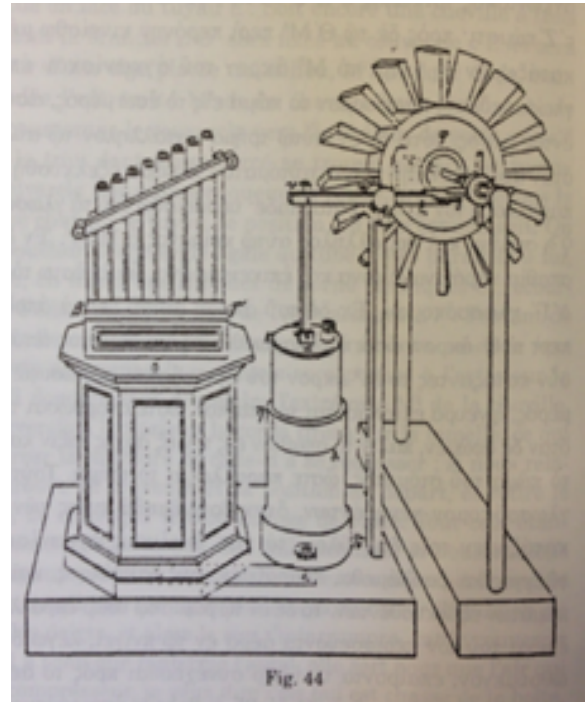
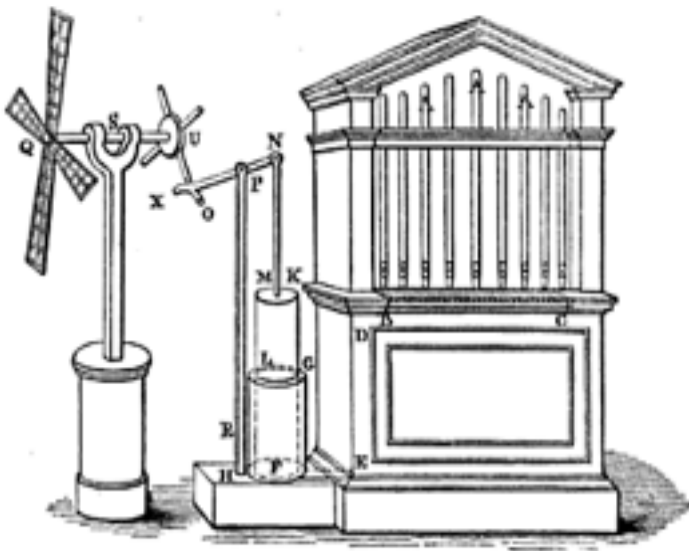
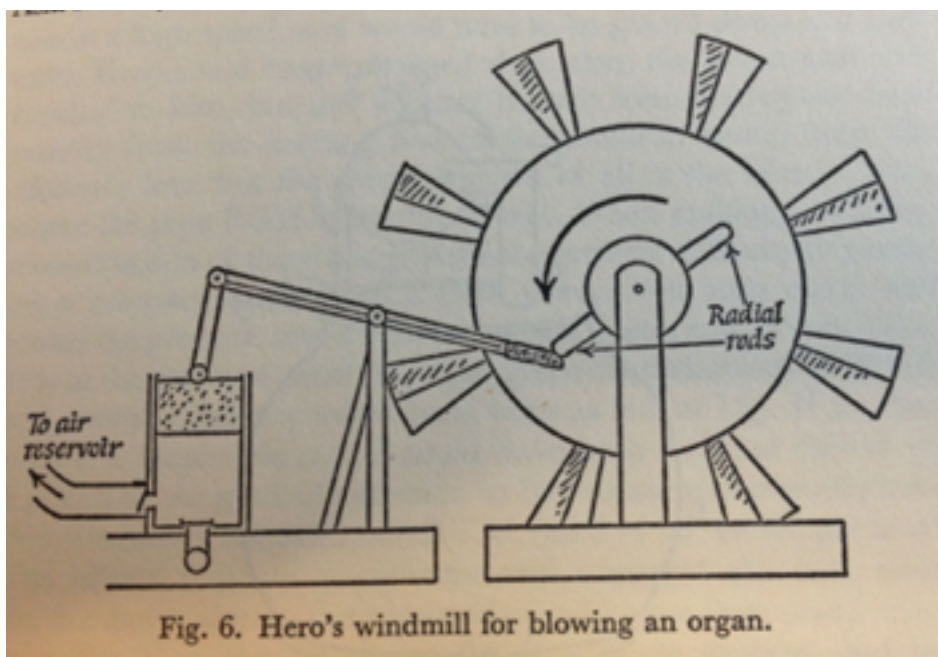
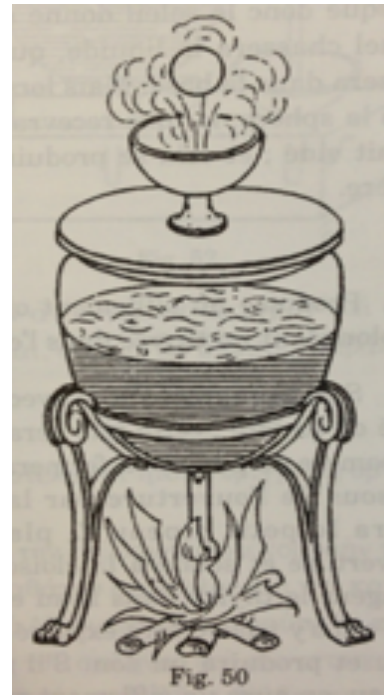


Figure 7: Image from Landels.1978.27. Landels has simplified the machine by removing a depiction of the organ altogether, which makes it easier to understand how it works. The vane turns, pressing down upon a wooden beam, which then raises a plug out a sealed reservoir, which then falls via its own weight, and forces air into the organ.



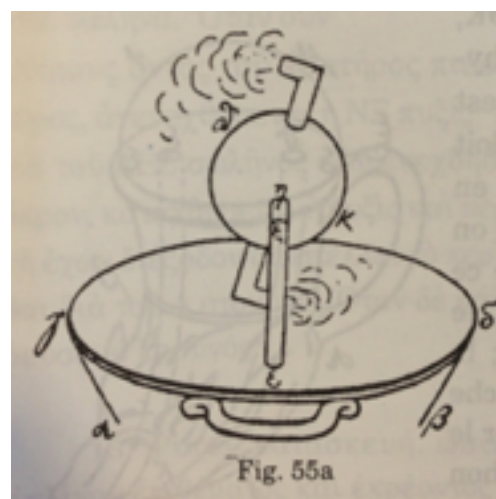
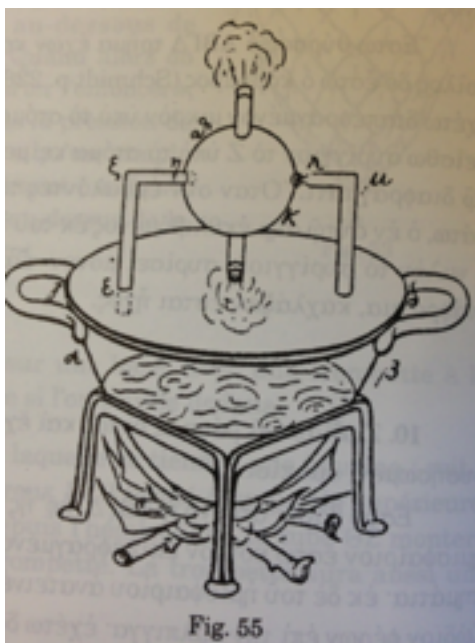
Machine 45: A jet of steam supporting a sphere

Figures 8 and 9: Images can be found in Woodcroft.1851.68 and Argoud.1997.137. Their reconstructions are distinctly different, and in this case Argoud seems more accurate. Woodcroft is overly elaborate, and does not include the fire and boiler, which Argoud presents very clearly,



Machine 50: The Steam-engine (or aeolipile)

Figures 10 and 11: Courtesy of Argoud.1997.140-1. I have placed these before Woodcroft and Landels' reconstructions, because they are very clear and show how the machine works effectively. The first image displays the boiler and fire below, and the bronze sphere from a forward angle. The second shows how the machine is capable of revolving, as the steam is blown in different directions by bent pipes.



Figures 12 and 13: Images from Woodcroft.1851.72, and Landels.1978.28. Woodcroft's version once more is missing the boiler, and is very unclear as to how the bronze sphere would turn. Landel's model is better, as shows the fire below, and displays the bent pipes. It does not show the liquid inside the boiler however, and how it rises into the sphere, as Argoud does.

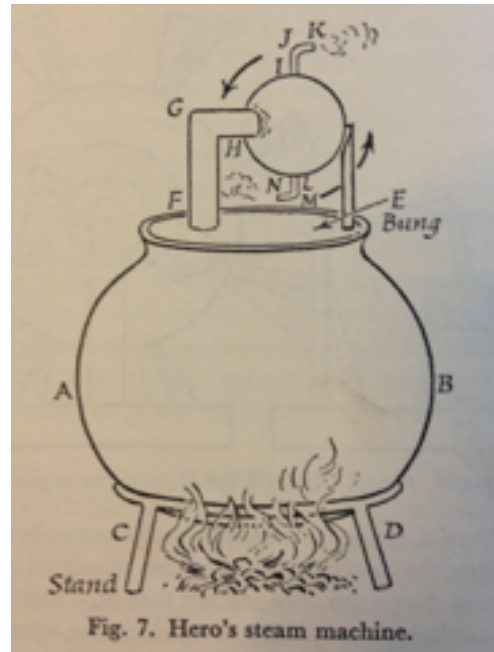
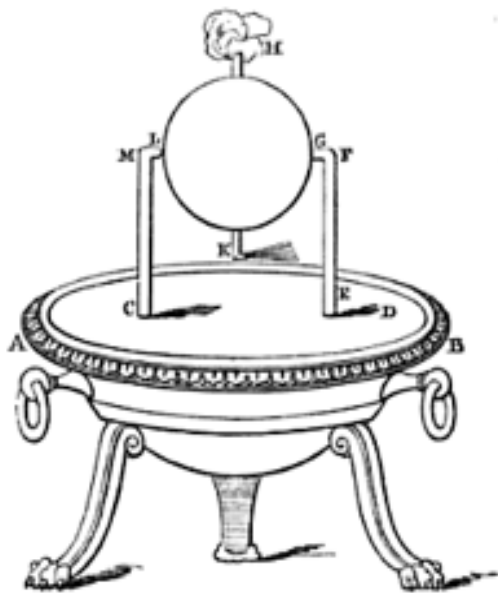
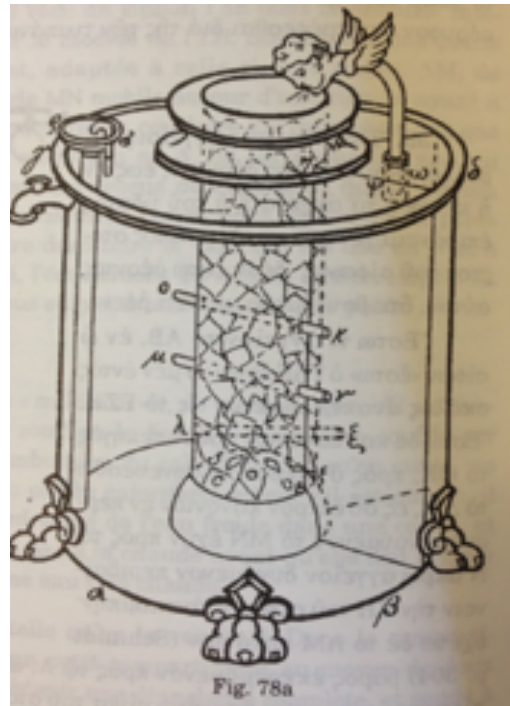
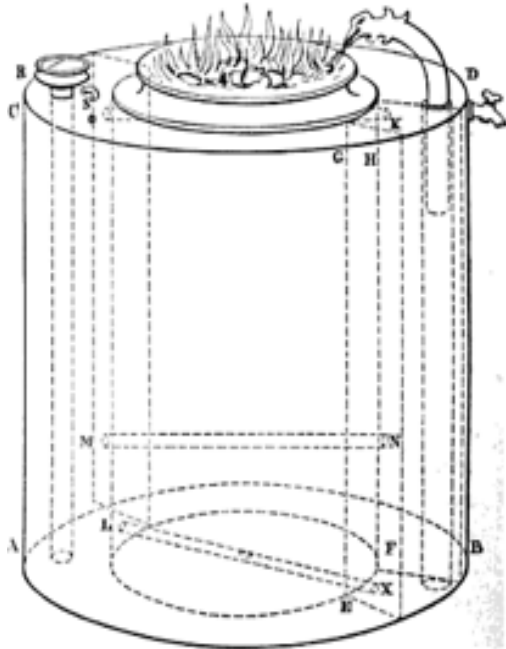


Figure 14: A modern reconstruction of machine 50 in movement, as built and photographed by John Bentley in 2007. Image (including front cover picture) can be found at: <http://modelengines.info/aeolipile/>



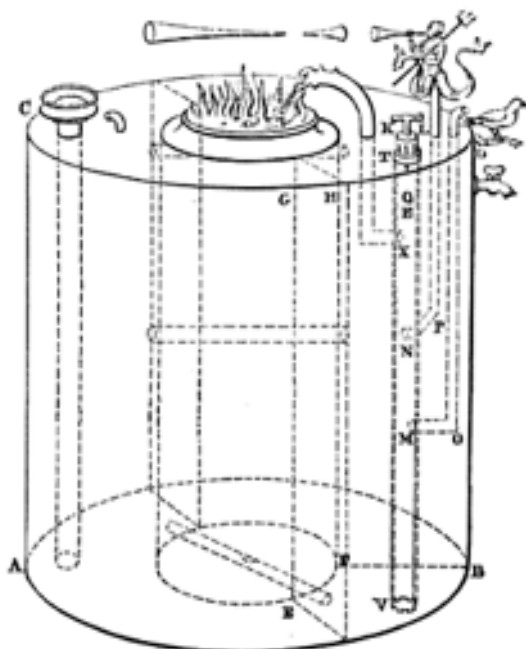
Machine 74: The Steam boiler

Figures 15 and 16: Images can be found in Woodcroft.1851.100 and Argoud.1997.176. Oddly enough, it is Woodcroft's version in this case that is easier to follow, as he shows the internal division, and the pipes that send the steam up to the snake. Argoud has strangely decided to change the snake into a winged cupid, despite Heron's description explicitly stating it is a serpent.



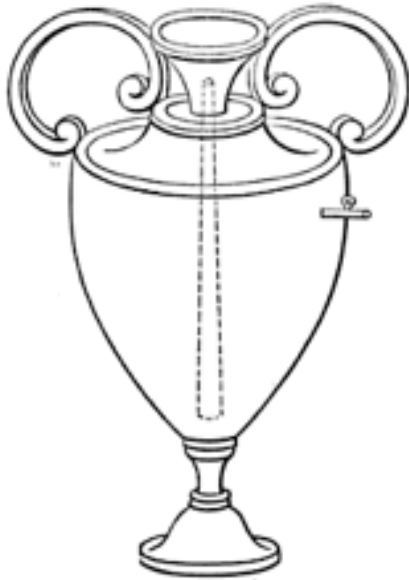
Machine 75: The more ornate steam boiler

Figures 17 and 18: Images from Woodcroft.1851.103 and Argoud.1997.180. The machine is the same as the previous, but includes a triton and a bird, made to produce sounds through steam being expelled.



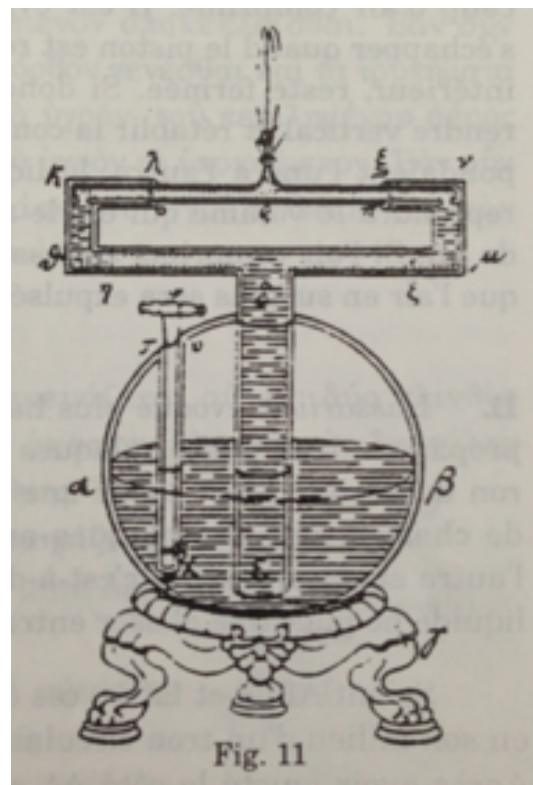
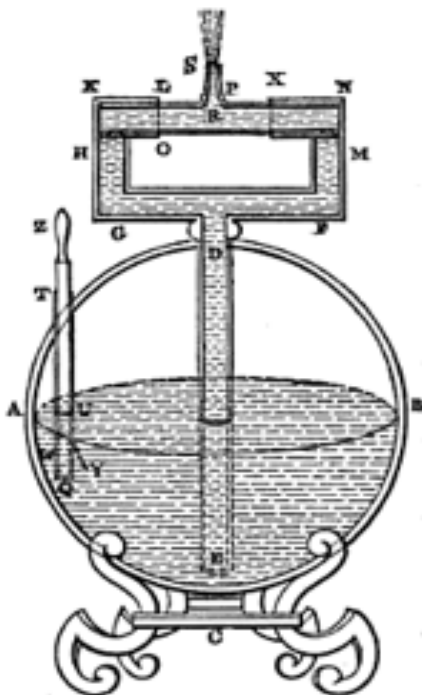
Machine 42: A water jet actuated by compressed air (the force pump)

Figures 19 and 20: Images from Woodcroft.1851.65, Argoud.1997.132. The tube needs to be stoppered at the top, then a hole in the side has water, then air inserted into it. After inserting a key to stopper that hole as well, release the tube at the top – water will spurt out. Both reconstructions show they end of the process with the key inserted, and do not show how the water is manipulated.



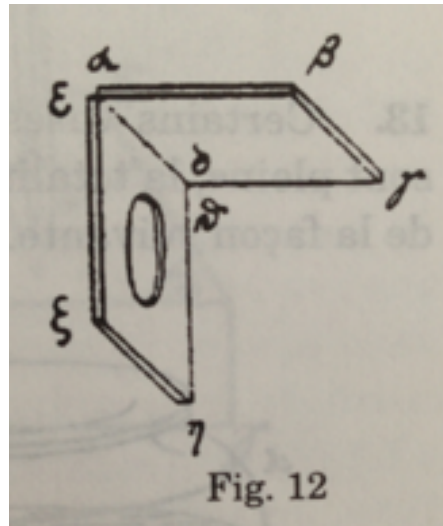
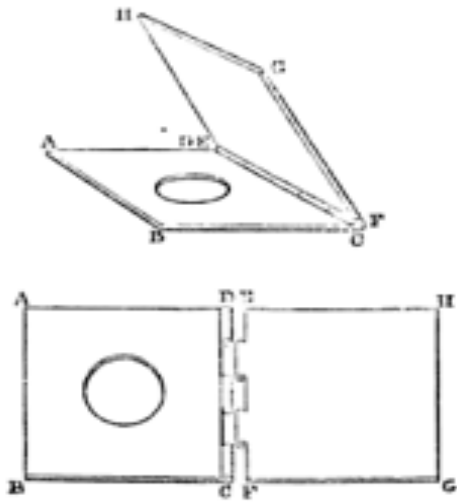
Machine 9: Water jet produced by mechanically compressed air (valve mechanisms)

Figures 21 and 22: Images courtesy of Woodcroft.1851.23 and Argoud.1997.67. The machine is very complex, and uses multiple pipes to force air into the sphere, which is built to withstand high pressure. Having no outlet, the air forces the water out of the passage on top. Both reconstructions are difficult to follow, as is Heron's text.



Machine 10: Valve for a pump

Figures 23 and 24: Images from Woodcroft.1851.25 Argoud.1997.69. This a closer look at the valve used in machine 9, which Heron's includes separately to better explain the machine. It is used to allow the air in, then to contain it.



Chapter 2: Entertainment

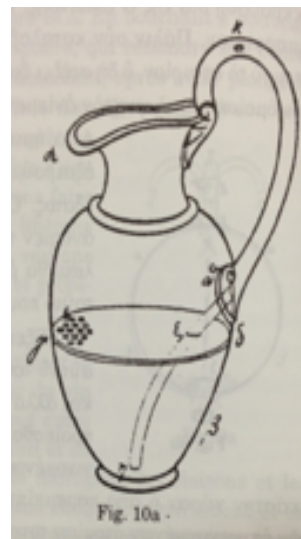
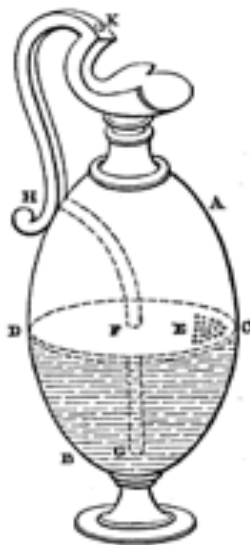
Figure 1: My compilation of drinking and sympotic entertainment devices from Heron's *Pneumatics*. There are 30 in total, from an overall 78 machines. Descriptions taken from Woodcroft's English translation.

Number	Description
6	A Vessel for retaining or discharging a liquid at pleasure
7	A Vessel for discharging liquids of different temperatures at pleasure
8	A Vessel for discharging liquids in varying proportions
12	A Vessel from which the contents flow when filled to a certain height
13	Two Vessels from which the contents flow, from a liquid being poured into only one
18	Drinking horn from which either wine or water will flow
19	A Vessel containing a liquid of uniform height, although a stream flows from it
20	A Vessel which remains full, although water is drawn from it
22	A Vessel from which a variety of liquid can be made to flow through one pipe
23	A flow of wine from one Vessel, caused by water being poured into another
24	A pipe from which flows water and wine in varying proportions
25	A Vessel from which wine flows in proportion as water is withdrawn
26	A Vessel from which wine flows in proportion as water is poured into another
32	A Vessel containing different wines, any one of which may be liberated by placing a certain weight in a cup
34	A Vessel from which liquid may be made to flow, on any portion of water being poured into it
35	A Vessel which will hold a certain quantity of liquid when the supply is continuous, will only receive a portion of such liquid if the supply is intermittent
39	Wine flowing from a Vessel may be arrested on the introduction of water, but, when the supply of water ceases, the wine flows again
41	A Vessel from which uniform quantities only of liquid can be poured
51	A Vessel from which flowing water may be stopped at pleasure
52	A Drinking horn in which a peculiarly formed siphon is fixed
53	A Vessel in which water and air ascend and descend alternately
54	Water driven from the mouth of a wine skin in the hands of a Satyr, by means of compressed air

55	A Vessel, out of which water flows out as it is poured in, but if the supply is withheld, water will not flow again, until the Vessel is half filled; and on the supply being again stopped, it will not then flow until the Vessel is filled
58	A Vessel from which a flow of wine can be stopped, by pouring into it a small measure of water
59	A Vessel from which wine or water may be made to flow, separately or mixed
62	A Vessel which emits a sound when a liquor is poured from it
64	A Drinking horn from which a mixture of wine and water, or pure water, may be made to flow alternately or together, at pleasure
65	A Vessel from which wine or water may be made to flow separately or mixed
66	Wine discharged into a cup in any required quantity
67	A Goblet into which as much wine flows as is taken out

Machine 8: A Vessel which discharges varying proportions of liquid

Figures 2 and 3: Reconstruction respectively from Woodcroft.1851.22 and Argoud.1997.64. Their models are fairly similar (although Woodcroft's is typically more elaborate) and both imagine the machine as a tall jug, with an inner partition and a large handle.



Machines 59, 64 and 65: Vessels that dispense either pure or a mixture of water and wine

Figures 4, 5 and 6: Reconstructions respectively from Woodcroft.1851.82, 89 and 90. All make use of compressed air and a siphon in order to expel liquids, similar to machine 8. Even Woodcroft's images, despite their differing forms, bear a resemblance.

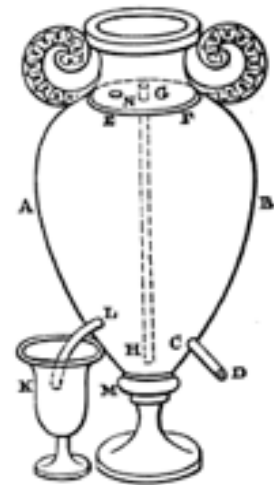
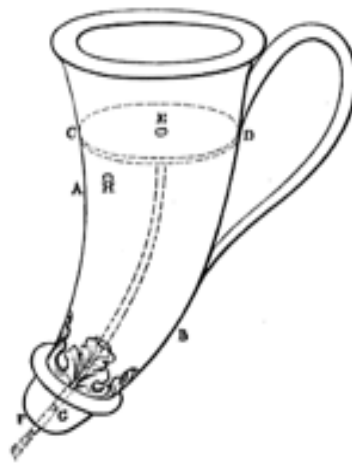
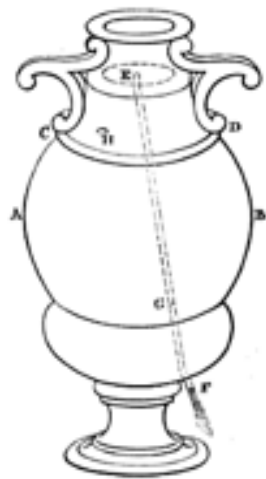


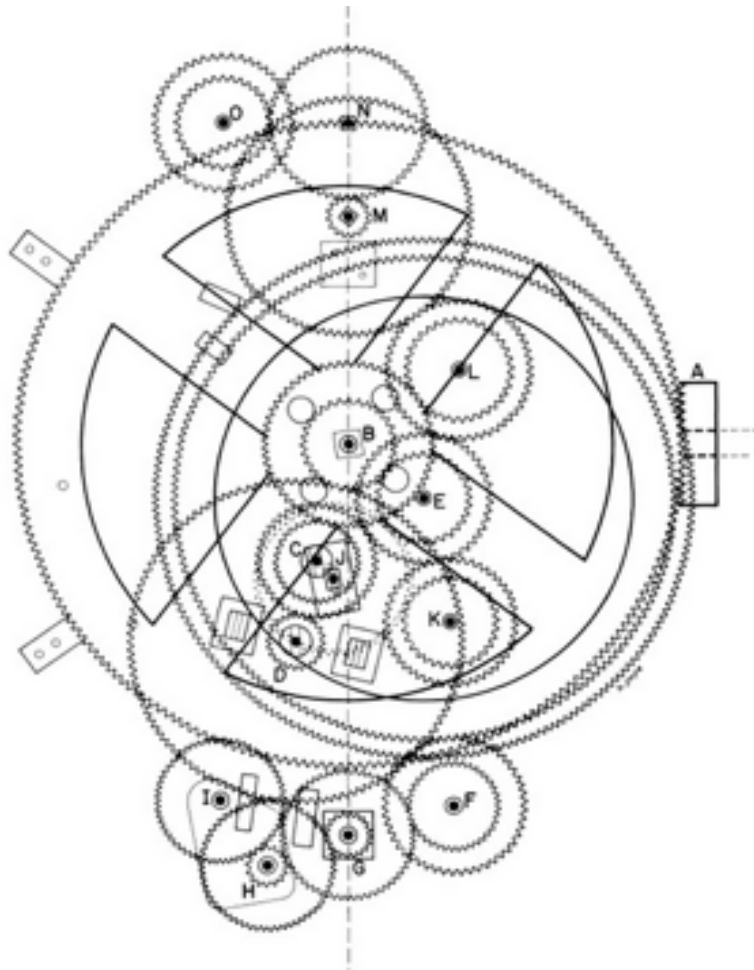
Figure 7: Rhodian sympotic kylix, 550-520 BC. Cup located in the Archaeological museum of Rhodes. The eyes on the side are stereotypical of sympotic vessels. Photo author's own.



Figures 8 and 9: The Lycurgus cup, Roman 4th century AD. As can be seen, the glass is green during normal lighting, but turns red when a lamp is lit behind, a result of the mixture of silver and gold within the glass. Images belong to the British museum and can be found at: http://www.britishmuseum.org/explore/highlights/highlight_objects/pe_mla/t/the_lycurgus_cup.aspx



Figure 10: Internal workings of Antikythera mechanism. Image provided by Price.1974.37. For more information on the device, Price's 1974 article is very informative. The mechanism comprised over thirty gears, and it must be in mind that this reconstruction is a model – the fragments are still being x-rayed today to discover more about how it functioned.



Figures 11 and 12: Parapegma inscription, and translation by Price.1974.46, 49. This is the most complete inscription left on the fragments of the mechanism. The only other significant section is the back door plate inscription. Despite this, the Parapegma inscription is still fairly corrupted.



- [Κ] . . . evening
- [Α] The Hya[des se]t in the evening
- Μ Taurus [be]gins to rise
- [Ν] Vega rises in the evening
- Ξ [The Pleiad]es rise in the morning
- Ο The Hyades rise in the morning
- Π Gemini begins to rise
- Ρ Altair rises in the evening
- Σ Arcturus sets in the [morning]

Figures 13 and 14: Back door plate inscription, with translation by Price.1974.47, 50. As apparent, most of the inscription is corrupted.

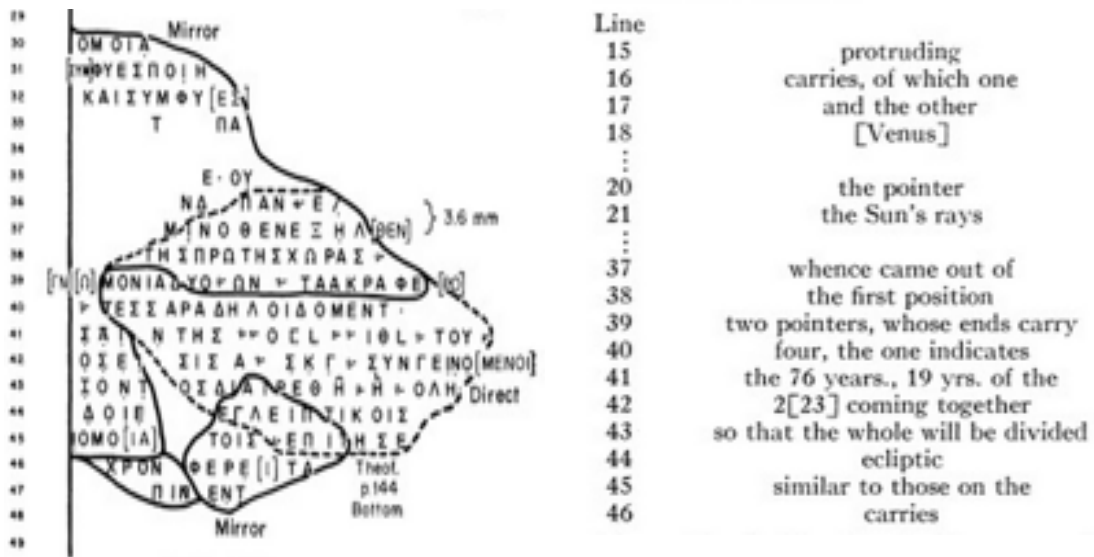


Figure 15: Bronze Ephebe found in the Antikythera shipwreck. It does not follow stereotypical body types, and the fact it is in bronze has led to scholars to surmise it is a Hellenistic original. It is currently located in Archaeological museum of Athens. Photo can be found at wiki images.



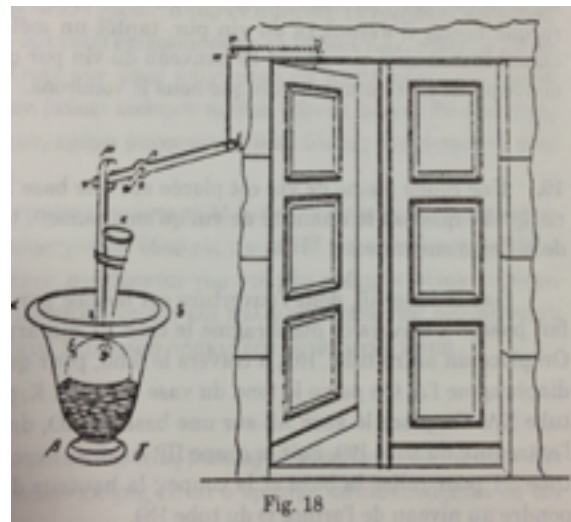
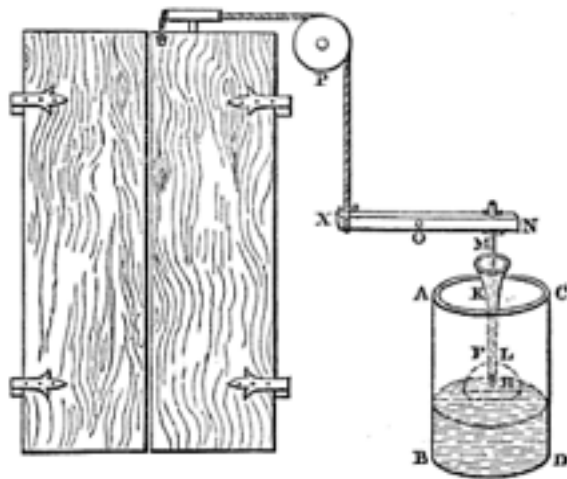
Figure 16: Photo of the Tower of the Winds, courtesy of Noble and Price.1968.356. The tower is located in the Roman Agora in Athens, and is mostly intact. As can be seen, depictions of the eight winds decorate the octagonal tower. Just below the deities were sundials, and there are two entrances. The mechanism for the water clock would have been located inside. It is mentioned by Vitruvius (1.6.4) and Varro (3.5.17) as having been built by Andronikos Kyrrhestes. A detailed description can be found in Price and Noble's article.



Chapter 3: Religion

Machine 17: A trumpet sounds on the opening of the temple door

Figures 1 and 2: Images from Woodcroft.1851.33, Argoud.1997.79. Both show the mechanism fully on display, rather than hidden as Heron's text implies it should be.



Machine 37: Temple doors opened by fire on an altar

Figures 3 and 4: Courtesy of Woodcroft.1851.57 Argoud.1997.113. Neither reconstructions are clear, although Woodcroft's is perhaps easier to understand. The fire heats up the air within the altar, which then forces liquid into a separate sphere, lowering a bucket and opening the doors via a pulley system.

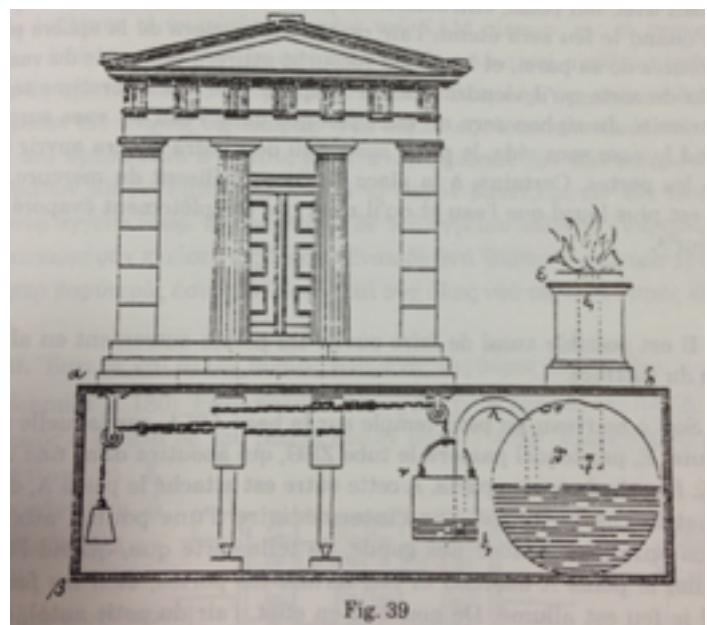
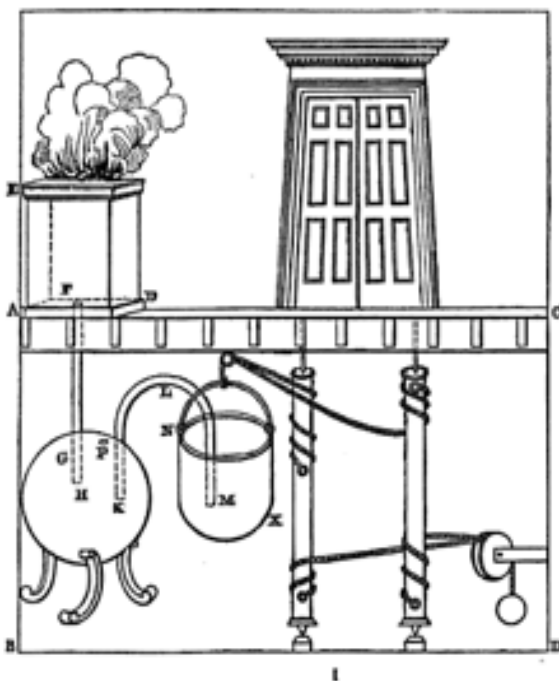


Figure 5: Rhodes and Osborne 102, Inscriptions at the Sanctuary of Asclepius at Epidauros. circa 320 BC. The first section is the original text, and then the translation.

θεὸς *vacat* τύχα [ἀγ]αθή.
 [ἰά]ματα τοῦ Ἀπόλλωνος καὶ τοῦ Ἀσκληπιοῦ.
 (i) [Κλ]εὸ πένθ' ἔτη ἐκύησε. ἅτα πέντ' ἐνιαυτοὺς ἤδη κυοῦσα ποὶ τὸν
 [θε]ὸν ἰκέτις ἀφίκετο καὶ ἐνεκάθευδε ἐν τῷ ἀβάτωνι ὡς δὲ τάχισ-
 5 [τα] ἐξῆλθε ἐξ αὐτοῦ καὶ ἐκ τοῦ ἱεροῦ ἐγένετο, κόρον ἔτεκε. ὅς εὐ-
 [θ]ὺς γενόμενος αὐτὸς ἀπὸ τῆς κρήνης ἐλούτο καὶ ἄμα τῇ μητρὶ
 [πε]ριῆρπε. τυχοῦσα δὲ τούτων ἐπὶ τὸ ἄνθεμα ἐπεγράφατο· "οὐ μέγε-
 [θο]ς πίνακος θαυμαστόν, ἀλλὰ τὸ θεῖον, πένθ' ἔτη ὡς ἐκύησε ἐγὼ γασ-
 τρὶ Κλεὼ βάρος, ἔστε ἐγκατεκοιμάθη καὶ μιν ἔθηκε ὑγιή". (ii) τριέτης

God. Good Fortune.
 2 Acts of healing of Apollo and Asclepius.
 3 (i) Cleo was pregnant for five years. When she had already been pregnant for five years she came as a suppliant to the god and slept in the Abaton. As soon as she went out from the Abaton and was clear of the sanctuary she bore a son who, immediately he was born, washed himself in the fountain and crawled around beside his mother. In return for this good fortune she wrote on her dedication: 'It is not the size of the tablet that should cause wonder, but the divinity, since Cleo was pregnant with the burden in her womb for five years until she slept in the sanctuary and the god made her healthy.'

Machine 21: The coin operated slot machine

Figures 6 and 7: Images from Woodcroft.1851.37 and Argoud.1997.84. Woodcroft's version, while more ornate, is in fact easier to understand in this case, as Argoud chose a narrow vase in which to fit the mechanism, making it harder to depict the inner workings. It is likely the machine belonged in a wider vessel, since space is needed for the inner structure.

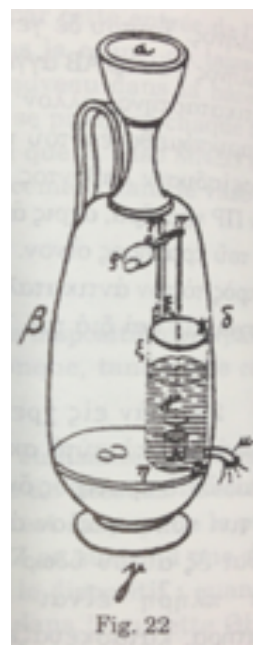
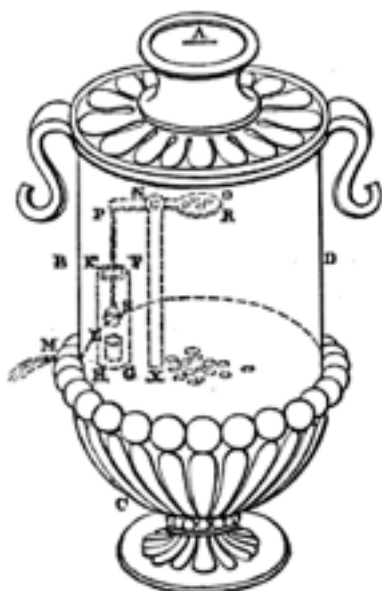


Figure 8: Rhodes and Osborne 97. It describes the Sacred Law of Cyrene, and is dated to the late 4th century.

Extract 1:

(iii) [ἀπ]ὸ γυναικὸς ἀνὴρ τὰν νύκτα κοιμαθὲς θυσεῖ ὃ [τ]-
 [ι κα] δῆλῆται· τὰν δὲ ἀμέραν κοιμαθὲς λωσάμε[os]
 [..... ε]ἴτι ὅπι κα δῆλ[ητα]ι, πλὰν ἢ ἐς [...]
 [-----]ταν· τὰν δὲ [-³⁴-]

11 (iii) A man coming from a woman, having slept with her by night, may sacrifice whatever he wishes. If he has slept with her by day, once he has washed, he may go -- wherever he wishes, except to --

extract 2:

(vi) αἶ κα ἐπὶ βωμῶι θύσει ἱερῆιον, ὃ τι μὴ νόμος θύεν, τ[ὸ]
 ποτιπίαμμα ἀφελὲν ἀπὸ τῶ βωμῶ καὶ ἀποπλύν-
 αι καὶ τὸ ἄλλο λῦμα ἀνελὲν ἐκ τῶ ἱερῶ καὶ τὰν ἱκ-
 νιν ἀπὸ τῶ βωμῶ καὶ τὸ πῦρ ἀφελὲν ἐς καθαρὸν·
 30 καὶ τόκα δὴ ἀπονηφάμενος, καθάρας τὸ ἱερὸν καὶ
 _____ζαμίαν θύσας βοτὸν τέλειν, τόκα δὴ θνέτω ὡς νόμ[os].

26 (vi) If someone sacrifices at an altar a victim which it is not customary to sacrifice, he is to remove from the altar the fat that remains and wash it away, and remove from the sanctuary the rest of the filth, and take away the ash from the altar and the fire to a pure place, and then, when he has washed himself and purified the sanctuary and sacrificed as a penalty a full-grown animal, let him sacrifice according to custom.

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