IDOLATRY AND INFINITY

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Of Art, Math, and God

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For

Theodora Sachs Aronson
lover of Art
teacher of Math
student of Judaica

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FIRST MATTERS

The humanities and mathematics, at present, are ensconced in a paradox. There is a resurgence of products directed to students and teachers purporting to make math fun to teach and learn. In the propaganda dispensed in the advertizing of these wares, from glossy workbooks to computer programs, software for tablets and such: knowing math, and liking it too, is freed of its otherwise nefarious marginalization in geekdom. It is as if single-handedly the spectre of math anxiety is exorcised merely with some fun-with-math tools. Maybe so.

Yet, in tandem with this frame of mind, there remains the ever present reticence of most readers to engage with any work containing explicit mathematical symbols. This viewpoint is summarized succinctly in a story from physicist/cosmologist, Stephen Hawking. While working on a popular account of his ideas, he was warned that for every equation he inserted into the manuscript he would lose half his readers, and so his international bestseller, *A Brief History of Time,* is equationless (except for one entry, $\mathbf{E = mc^2}$). Correspondingly, it seems, some science writers almost pride themselves on eliminating the dreaded math. But why should equations stop readers in their tracks any more than words they do not understand? I do not have an answer.

Instead, bolstered by the "don't be afraid of math" trend, I am boldly joining together a humanities essay (on idolatry, art, and theology) with one explicitly voyaging into geometry, algebra, calculus, and even set theory – all of which, nevertheless, I endeavor to explain clearly and plainly for the novice reader. My mantra?: paradox, be damned. This story is too vital and appealing to let a little paradox get in the way.

Furthermore, that this tale only exists in fragments, is itself indicative of the dichotomy (between math and the rest). Yes, there are histories of idolatry and there are histories of infinity; yet here for the first time the two are inimitably woven into one.

* * *

The spectre of idolatry has haunted the three dominant Western religions since the prohibition was put forth in the biblical Second Commandment, often flaring up in the physical destruction of objects deemed as idols, and which most recently materializing in 2001 when the Taliban in Afghanistan dynamited two large statues of the Buddha. The story of iconoclasm – the banning and sometimes smashing of what today are *objects d'art* – runs from biblical times through the iconoclastic episodes in Islam and Christianity, even into modern times during the French Revolution. Perhaps a surprising thesis of this little book (really a long essay) is that a conceptual and secular form of iconoclasm continued, as expressed in the revulsion of illusionism in Modern Art of the 20th century.

The second fragment weaved into the previously unwritten story is the often concurrent awe and dread of infinity. The awe factor was an essential component in theology among the three religions. God/Allah – the Being who banned idols – was identified as THE infinite by theologians, philosophers, and even many mathematicians. The dread factor arose in the mathematics of Pythagoras, with his discovery of irrational numbers. What he saw as an illogical number grounded in the idea of infinity (all plainly explained here for even the reader with latent math anxiety) led him to loathe and try to hide what he discovered. But it got out and, with Pythagoras's authority, a phobia around any idea involving infinity dominated ancient thought – witness the troubles over Zeno's paradoxes, explained here too – with only rare exceptions (such as displayed by the genius of Archimedes, who brazenly

met the infinite head on). This narrative runs through the Middle Ages, surfacing perhaps unexpectedly in the visual space of Renaissance art, where God was identified with the vanishing point in geometrical perspective, thus linking infinity and God in a unique way. All of which concurs with the subtitle of the book: *Of Art, Math, and God*. The woven tale is completed with an explanation of calculus (the realm of the infinitesimal), an elucidation of the modern cosmos (the realm of an infinite universe or infinite universes), and an elementary exposition of the discovery of transfinite numbers (the realm of infinite infinities).

Readers familiar with aspects of iconoclasm may be unaware that it was and remains a part of Modern Art – along with the link to the concept of infinity. Math and science buffs familiar with some aspects of infinity may first learn of its link with Renaissance art, as well as the long association with theology, right up to the present. With visual aids for the uninitiated, may this book grant the art lover access into a previously uncharted territory – a math venture to stretch the mind.

Paradox surmounted?

* * *

A note on my idiosyncratic notation. All materials cited at end of each chapter (as below) are fully listed in the Bibliography. The dates for material obtained from the Internet are cited as: Author (ac-Year), the year being when it was accessed. All quoted material is cited as, e.g., Topper [Einstein quote] (2013). Figure 4.3 means the third figure in Chapter 4. The diagrams and figures that I drew were done so to avoid potential copyright infringements. Most images from art and architecture that are discussed in some detail are reproduced in the book. Sadly, much 20th century art entails copyright complications with fees that would make the price of this book beyond what I believe is reasonable. Luckily, extensive samples of the works of all artists talked about are very quickly available over the Internet – and almost always in color.

* * *

◊ **Readings**: Hawking (1988).

1. IDOLATRY I:
THE MYTH OF JEWISH ICONOCLASM

In the Hebrew *Bible*, when the Israelites routed their enemies in battle, they made sure to smash their idols to smithereens in order to demonstrate that these material gods were powerless in the face of the almighty invisible God of Israel. In March 2001 the Islamic Taliban in Afghanistan dynamited two large statues of standing Buddhas carved into the side of a cliff in the Bimiyan valley. In that valley along the famous Silk Road – the important caravan route linking markets in China with Western Asia – these Buddhas silently stood since the 6th century CE, until being blown to bits as idols in the name of Islam. New method, same result – shattered idols – and for the same reason, God/Allah forbids the worship of false gods.

Iconoclasm – from the Greek word, icon or image; meaning the prohibition or destruction of images, either figuratively or literally – has a long history, from today's Taliban and reaching back three millennia (at least) into the ancient Near East. A written source of the Taliban's validation for their demolition is the same as the ancient Israelites: the injunction against images in the Hebrew *Bible*, specifically in the *Torah* (the first five books from Genesis to Deuteronomy). In the book of Exodus, when God speaks to Moses on Mt. Sinai, the Ten Commandments are delivered on two tablets and so these ten injunctions appear in the text for the first time. They crop up again in Leviticus (slightly scrambled) and further in Deuteronomy – just to make sure, supposedly, that the children of Israel get the message.

Unfortunately, despite the repetition of these rules, the Deity never bothered to number them specifically, beyond noting that there were ten – and so, within the Judeo-Christo-Islamic traditions, there are several ways of numbering the individual commandments depending on how the list is divided up. The iconoclastic injunction appears near the start of the list and in Judaism it is the Second Commandment:

> You shall not make for yourself an "idol," or any likeness of what is in the heavens above, or on the earth below, or in the waters under the earth.

The Hebrew word that I have translated as idol is *pesel* (פסל), variously translated as idol, image, or graven (i.e., carved or sculptured) image. This particular prohibition is repeated (with variations) at least seven more times in the *Torah* and, if taken literally, it is no wonder that the Jews were often called the people of the book, the implication being that their religion was imageless.

One clear cut rationale for this prohibition is the dramatic contrast between the God of the Hebrews and the gods of the pagans. Listen to this description of those other gods in Psalm 115:4-7:

> Their idols are silver and gold, the work of men's hands.
> They have mouths, but they speak not; eyes they have, but they see not;
> They have ears, but they hear not; noses have they, but they smell not;
> They have hands, but they handle not; feet have they, but they walk not;
> Neither speak they with their throat.

In contrast, the Hebrew God was immaterial, invisible, and unique. As such, this god/God was unrepresentational. As the prophet Isaiah rhetorically put it: "To whom then will you liken God, or what

likeness will you compare with Him?" (Isaiah, 40:18). From the diktat of the Second Commandment there is an historical thread running through Christianity to Islam and in due course to the obliteration of those Buddhas previously standing (in both senses of the word) along the Silk Road.

From its beginning in the 7th century CE, Islamic art was nearly imageless. No human-like or animal forms were permitted; at most we find foliage of very stylized and unidentifiable plants, weaving and intertwining in intricate patterns to which Europeans later bestowed the term arabesque. The other dominant motif in their art was based on abstract geometrical designs (discussed in the second part of Chapter 3).

Islam, founded by the Prophet Mohammed, followed Christianity chronologically, but was linked to Judaism conceptually. In the Book of Genesis (16-17) is the story of Abraham (Ibrahim, in Arabic) and his wife Sarah, who were childless and so Sarah gave Abraham permission to father a child with her Egyptian slave-servant Hagar. A son was born to Abraham and Hagar, who she named Ishmael. Subsequently, several years after Ishmael's birth, when Sarah was 90 and Abraham 100, Sarah gave birth to a son by Abraham, who she named Isaac. After weaning Isaac, Sarah commanded Abraham to banish Hagar and Ishmael into the wilderness, although the *Bible* gives no give reason for her demand. Abraham initially resisted Sarah's order, for he was devoted to his son by Hagar, but eventually he gave in and sent the mother and son on their way. The *Bible* speaks briefly of their ordeal through the wilderness and God's protection of them as they eventually settled down, with Hager finding Ishmael an Egyptian wife. In time a "great nation" arose from Ishmael's 12 children – an account that parallels the 12 children of Jacob, from which arose the 12 tribes of Israel, the other great nation (Genesis 21). Ishmael only appears in the *Bible* once more; about 72 years later at the death of Abraham (Genesis 25). The implication is that they kept a father-son relationship over those many years, yet nothing about this is in the biblical text.

That narrative gap is filled in the Muslim Holy Book, the *Qur'an* (formerly transliterated as the *Koran*), where the Ishmaelites are identified as the Arab nation and with Hagar the great matriarch. Today the center of Islamic worship is the black stone within the *Kaaba* (the cuboid shaped structure) in the Grand Mosque (Masjid al-Haram) in Mecca, the place of an annual pilgrimage (the Hajj). According to the *Qur'an* this stone from heaven (probably a meteorite) was given to Ibrahim, and he and Ishmael built the *Kaaba* and first mosque. Ibrahim even instituted the *Hajj* as well as the ritual of circling the *Kaaba* seven times (*Qur'an*, 2:127; 14:39; 22:26-27).

This continuation of the biblical narrative within the *Qur'an* therefore links up Islam with the historical beginnings of Judaism (a gap of over 2½ millennia, if we take the biblical narrative literally). This link was reinforced by, for example, this parallel: Ibrahim and Ishmael, when building the *Kaaba* to enclose the black stone, smashed the idols of the pre-Islamic polytheistic tribes (*Qur'an*, 21:51-73); similarly, according to tradition, in his return to Mecca after his expulsion, Mohammed circled the *Kaaba* and destroyed the idols of the pre-Islamic tribes, thus cleansing the site. So were planted the seeds of iconoclasm within Islam.

Similarly, Christianity, rooted in Judaism, was confronted with the problem of iconoclasm. There were two main episodes of iconoclasm in Christianity when the Second Commandment was invoked in the censure of imagery. The first was in the late-8th and early-9th centuries CE in the Byzantine church, a legacy whose remnants are seen today in the rigid stylization of what are called Byzantine icons (see the first part of Chapter 3). The second, and more virulent, episode of iconoclasm occurred during the Protestant Reformation in the 16th century (Chapter 5), when scores of stained glass windows, statues, altarpaintings, and any other image carrying objects were defaced, smashed, or burnt during the revolt against the "idolatry" of the Catholic Church. The Reformers' justification of this massive vandalism – which they saw (erroneously, as we will see) as a repeat of what happened in the Byzantine church centuries before – was the behavior of the Israelites against the pagan idols as por-

trayed in the Hebrew *Bible*. The Israelites were commanded by God to "…break their pillars [idols] in pieces" (Exodus 23:24); or further to "…break down their altars, and dash in pieces their pillars, and hew [cut] down their *Asherim* [idols of the fertility goddess Asherah], and burn their graven images with fire" (Deuteronomy 7:5). Ever since, some branches of Protestantism remain imageless in their churches.

These iconoclastic interpretations of the Second Commandment among Christians and Muslims reflected back on its origin in Judaism. Accordingly, there arose the widespread belief that the people of the book were indeed just that, with a pictureless book. It is true that the main text used in the synagogue today, the *Torah* – which remains in its ancient format, namely in the form of a scroll – is composed entirely of Hebrew text, a text that carries the weight of centuries of tradition. As such there is a dedication to reproduce diligently the word of God as precisely as possible – all of which leads to the repetition and duplication of this text. Although *Torah* scrolls come in different sizes (namely, height and total length) all are the same in several fundamental ways. All are written in the same Hebrew script (almost all letters and diacritical marks are identical; at most there are minor difference in the scripts of just a few letters between the Ashkenazi [German/Eastern European] faction and two Sephardic [Spanish/Middle Eastern] branches); all have the same number of columns and rows (remember, a scroll has no pages); the same words begin and end each row; the same rows are at the top and bottom of each column; even the ratio of the black ink to the white empty space is supposed to hold to a fixed ratio (50/50). It is as if each *Torah* scroll is a photocopy of the original, with only the enlarge/reduce adjustment changed. There are even standardizations for the parchment and ink, as well as the needle and thread used to sew the parchment sections together. The *Torah* scroll brings to bear a fixation with the written word – in both content and form – with a vengeance. It follows obviously that the *Torah* has no pictures or images of any kind. Pictureless too are the various Talmudic textual interpretations of the *Torah*. It is no wonder, at this point in this survey of ritual, that Jews would be called the "people of the book."

The Second Commandment, however, has not only been interrupted as being about picture books, it also was said to encompass imagery throughout religious ritual, and it is within this larger framework that we find the ancient Israelites were not averse to producing likenesses of what is on earth, in the waters, or even in the heavens. Put simply and bluntly: the biblical injunction against images notwithstanding, the practice in life and worship among Jews from the start was steeped in visual imagery.

The evidence comes from a close reading of the biblical text plus modern archeological excavations. To be sure, the iconoclastic injunction was invoked when the Israelites routed their enemies and smashed the idols they worshiped. But within their own rituals of worship, imagery was freely rendered. One of the first artists mentioned in the *Bible* is Bezalel, the artist/architect of the Ark of the Covenant and the accompanying Tabernacle in the desert. There are detailed descriptions of not only the floral and faunal images he made, but especially of two statues of winged cherubim made of gold that were guarding the Ark containing the precious tablets given to Moses.

Statues of gold are surely important artifacts in support of the historical evidence for Jewish imagery (even if only described in the text). But what specifically are cherubim (singular, cherub)? Regrettably, we do not know precisely. The word cherub is first used in Genesis, when Adam and Eve are driven out of Eden and the East Gate is said to be guarded by two cherubim, but there is no physical description of them. Moreover, there is no way of invoking an image from the Hebrew root of the word. Attempts have been made to relate it to similar words in Babylonian and other neighboring cultures, but there is scant evidence and no scholarly consensus on this. The most likely mental image is that of composite beings found throughout ancient Near Eastern art: those having animal bodies, human heads, and wings (such as the Sphinx), and used to guard palaces and temples. An edifying example is from the vision of the prophet Ezekiel (1:1-11 & 10:1-20) who saw four winged cherubim,

each with four faces: man (front), lion (right side), ox (left side), and eagle (back). (Later, Christianity borrowed the term cherub for their image of a type of angel, but to impose that imagery on earlier Jewish art would be anachronistic.)

These cherubim, whatever they were, that guarded the Ark in the desert reappear in the Temple in Jerusalem, built in the 10th century BCE. There are detailed descriptions of the architecture of Solomon's Temple in First Kings (6 & 7): here are further explications of the carved and cast art images used throughout the building – relief carvings of palm trees, flowers, and cherubim, plus bronze castings of pomegranates, lions, and oxen – indubitably these are descriptions of a plethora of imagery. Of considerable consequence are the statues within the holy-of-holies, where the Ark containing the two tablets of stone was kept. This Ark was guarded by flanking golden cherubim sculptures, their wings extended and touching over the Ark and spanning the entire wall and touching on both sides of the room. The width of the sanctuary was twenty cubits (about thirty feet), and the heights of the cherubim were ten cubits (about fifteen feet), with open wingspans of ten cubits each. What a commanding and imposing mental image this conjures up. If nothing else, this formidably contradicts the concept of Jewish opposition to imagery – and in the holy-of-holies, no less.

Biblical literalists see the parallel stories of the placement of these statues guarding the desert Ark and then guarding the Ark in the Temple in Jerusalem as an indication of continuity in the ritual practice. Modern scholars, however, view the Exodus story is an embellishment of an actual escape among only a handful of Israelites from pharaohic Egypt, since the details of the account are substantially impossible for a rag-tag group wandering about in the desert. The enhanced Exodus version, they argue, was composed probably during the time of Solomon's Temple in order to justify imagery, by supposedly tracing it back to the original Ark. Thankfully, the truth of either interpretation is extraneous to the argument here; suffice to say that imagery was an integral part of the ideology or scriptural format of Judaism.

The Temple of Solomon was destroyed in 586 BCE by the eastern army of Nebuchadnezzar, which resulted in the loss of the Ark and its contents (supposedly the Ten Commandments). Consequently, the ensuing period of exile of the Israelites was called the Babylonian captivity, which lasted until about 538 BCE, with their return to Jerusalem and an eventual rebuilding of the (Second) Temple around 520 BCE. The Second Temple lasted until the Jewish revolt against Roman rule (66–70 CE), with their defeat under the Roman general Titus. Later Titus became Roman emperor and erected a Triumphal Arch in Rome. On the interior of the Arch of Titus is a relief carving showing the spoils of war; namely, Roman soldiers bringing back artifacts looted from the Temple. The first large scale material evidence in contradiction of Jewish iconoclasm is that relief carving (Figure 1.1). Although the relief is badly worn, still conspicuous is a very large menorah (the seven-branched lampstand) carried on the shoulders of several soldiers. Importantly, on the base of this Jewish artifact there are five barely visible panels with depictions of animal like creatures, supplementing any textual descriptions of imagery. (Sadly, they are not visible in Figure 1.1; enlarged versions may be found on the Internet.)

The defeat of the Jewish rebels by the Romans led to the Diaspora, the dispersal of Jews throughout the ancient world, with a large number going to Rome as slaves and later set free. They brought with them the practice of burying their dead in hillside caves, as they had done on the hills of Jerusalem and throughout ancient Judea. In and around Rome there were natural caves, the catacombs, which Roman Jews extended and dug deeper, and in which they buried their dead. (Later Christians, who are often identified with the catacombs, used other caves for the burial of their martyrs and possibly as places of worship, since their religion was banned, whereas Judaism was not; more of this in Chapter 3.) Dated between 100 BCE and 300 CE, there are six Jewish catacombs which are identified by the mural paintings on the walls showing the Ark (containing scrolls), meno-

rahs, rams' horns, palm branches, and other symbolic objects associated with ancient Judaism. There are also similar relief carvings on coffins and tombstone. The style used is based on Greco-Roman images, which is not surprising since it was the art ubiquitous in the Roman culture, just as the writing found is the vernacular Greek or Latin (seldom Hebrew).

Figure 1.1 Arch of Titus – relief carving (Rome)

Photo Credit: Scala/Art Resource, NY

Yet it is a bit of a startle to find pagan symbols among the religious ones, such as a nude youth with wings and garland on his head (a winged victory), clearly borrowed from Greco-Roman art. Some have multiple meanings: a young man carrying a sheep on his shoulders is a pagan symbol, but the textual image is found the book of Ezekiel (34: 1-19), where God presents Himself as a shepherd protecting His people, an idea that appears later in Christianity with Jesus as the "good shepherd." As material historical evidence for Jewish imagery, other small items unearthed recently in Israel and elsewhere in the Middle East (ivory carvings, statuettes, coins, and such) further supplement these Jewish artifacts from Rome.

More and even larger material records exist in the archaeological excavations of ancient synagogue floors, which show an extensive quantity of mosaic tiling filled with imagery portraying the Zodiac, calendars, and Jewish symbols. One of the first and most important findings took place in the early 1930s in present day Syria, in what was the Roman town of Dura Europos, where the remains of a synagogue were dug out of the earth. Dura was an important garrison town near the Euphrates River along a well-traveled road about halfway between Babylon and Antioch; it was also a stop off point

on the way to either Damascus or Tiberius. In the mid-3rd century CE, the synagogue was filled with dirt by the Romans in anticipation of an attack by the Sassanians (the last rulers of Persia before the Arab conquest); it was part of a wall of defense that proved to be futile.

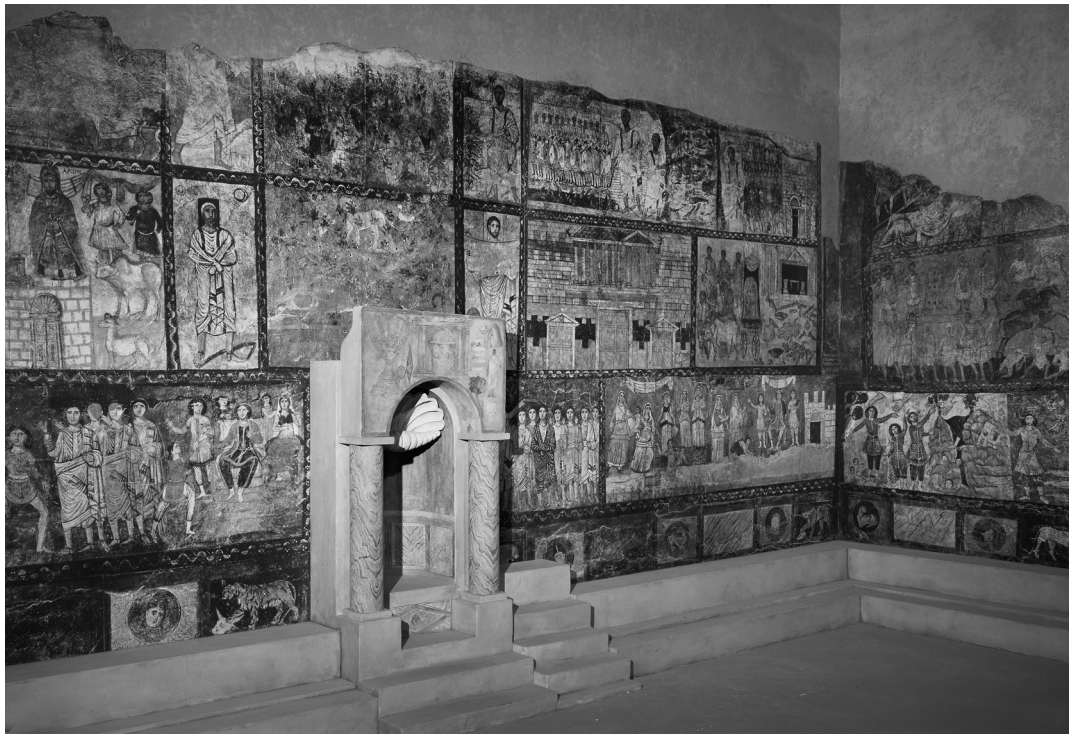

Figure 1.2 Replica of Dura synagogue (original in Damascus)

Photo Credit: Erich Lessing/Art Resource, NY

The act may have been futile for the Romans, but it was momentous for posterity. The Dura synagogue interior was emblazoned with mural paintings depicting Biblical stories on all four walls (Figure 1.2). The dirt fill preserved about half of this art until archeologists unearthed it in the 1930s. After excavation, the synagogue was moved and reconstructed; it is now a major exhibit in the National Museum in Damascus. As seen in Figure 1.2, much of the West wall is preserved; also, about half of the north and south wall murals are still visible.

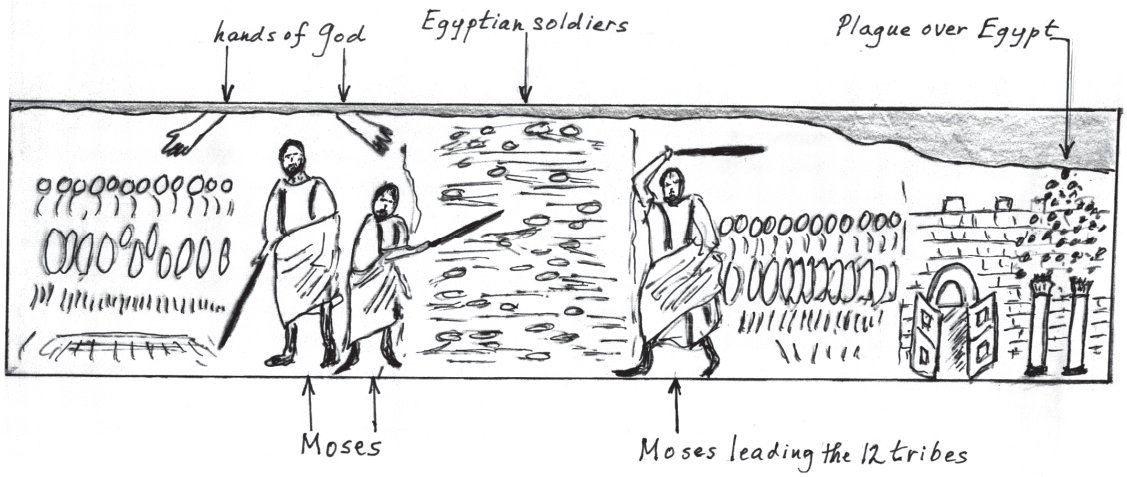

Figure 1.3 Mural of Moses and the Exodus

As an example, one story portrayed is the Exodus from Egypt with Moses leading the Israelites across the Red (or Reed) Sea, which is on west wall in the upper right. This wall alone gives the lie to the concept of an historical Jewish iconoclasm. The Exodus picture is important in other ways. It is one of the first visual images we know of that depicts a story as a continuous narration; that is, the story is told as a temporal sequence of scenes in chronological order (like a present day comic strip; but from right to left, since Hebrew is read in that direction). Figure 1.3 is a schematic diagram of the several overlapping panels. On the far right is a town, with something seemingly falling from the sky (one of the plagues, perhaps hail?). Moses leading the twelve tribes (count the heads!) from Egypt follows this. Note that Moses (who appears three times in the narrative) is wearing a Roman toga and carrying a staff with which he parts the Red Sea. After the Israelites safely pass through, he uses his staff to command the sea to close up and drown the pursuing Egyptian soldiers. The last panel has the twelve tribes finally on dry land, and Moses leading them toward freedom from bondage. Significant in the last two panels are the open palmed hands of God, unambiguously coming from above (possibly out of the clouds) facilitating this momentous event. Thus even the Deity is depicted, but only God's hand.

Such explicit chronological narration rarely appeared in pagan art. Of course, it is a device used today in comic strips, but more immediately relevant is that it was adopted and later used extensively throughout Christian art for narrating *Bible* stories. As biblical scholar Herbert Kessler put it, when Dura was excavated in the 1930s "the synagogue appeared to hold the key to an understanding of the formation of Christian imagery"; and he continued in 1990, "…i]t still does." Other such stories depicted in Dura are the infancy of Moses, the binding of Isaac, Moses giving water to the twelve tribes, Aaron blessing the Temple, the story of Purim, Jacob's dream, and more.

Even before the Dura Synagogue was found, in Galilee the Beth Alpha synagogue was unearthed but dated later; it is from the early-6th century. The art, as with most subsequent discoveries, consists of a large mosaic floor: this one contains both Jewish and pagan symbols. There is a round Zodiac set in a square with the four seasons at the corners, which shows the role of reckoning time (think of religious calendars keeping track of the cycle of rituals and holidays). Also, an Ark is depicted, flanked with menorahs, lions, palm branches, and other symbols; and the troubling tale of the binding of

Isaac by his father completes the floor. The excavations of numerous similar sites continue throughout present day Israel and other Middle Eastern countries, as more and more images emerge to contradict the iconoclastic thesis, despite what the Second Commandment text said.

Apparently the ancient Israelites did not read the injunction as literally as others later did. One probable source of the tempering of the iconoclastic restriction is the fact that each presentation of the commands in the biblical text is invariably followed by a caveat not the bow down to the images or not to serve them in any way, because the Hebrew God is a jealous God. Listen again to the verse quoted above, but with the next line added:

> You shall not make for yourself an "idol," or any likeness of what is in the heavens above, or on the earth below, or in the waters under the earth. You shall not bow down to them or serve them. For I the LORD your God am a jealous God….

A similar caveat ("lest you be drawn away and worship them and serve them…") is found after other versions of the Second Commandment. The implication is that images may be crafted as long as they are not artifacts of worship – which is certainly a reasonable standpoint, if indeed the Deity is a reasonable Being (as one may hope). This more nuanced interpretation would explain both the Second Commandment and the wealth of images throughout Jewish history. Put bluntly, it is not God's fault that some believers within Judaism and later Christianity and Islam failed to read the *Bible* closely enough to see the caveats.

So, in sum, we find that throughout Jewish history the people of the book supplemented their words with pictures, unabashedly and prolifically. Nevertheless, and despite all the evidence to the contrary, out of the iconoclasm within Christianity and Islam there arose the myth of Jewish iconoclasm – a false historical "fact" that continues to be believed and affirmed in popular writings, even amongst those who should know better.

* * *

◊ **Readings**: Besançon (2000); Brubaker (2012); Goodenough (1965); Kelley (1994); Plaut [biblical quotes] (1981); Simpson (2010); Topper (1991); Weitzmann and Kessler (1990).

2. INFINITY I:
PYTHAGORAS AND THE PHOBIA OF INFINITY

In ancient Greece culture, about thirty years after the construction of the Second Jewish Temple in Jerusalem, the notable philosopher/mathematician/logician, Zeno, was born. He eventually settled in the Greek colony town of Elea (present day Velia in southern Italy on the Tyrrhenian coast), and he became known as Zeno of Elea, famous for composing a series of paradoxes that still puzzle the mind.

Here is one. You are standing 20 units from a wall. You wish to walk to that wall. To get there you must walk half way, 10 units. As you do, you get closer. But to reach the wall you need to walk half way again, 5 more units, which you do. You are still getting closer, but not yet at the wall. To get there you must walk half way, as before, and you now are 2½ units away. But you still are not at the wall, although getting much closer. So you walk half way once more…. Do you see a pattern? Do you see a problem? You will always need to go half the distance to the wall, and this process is never ending. No matter how close you come, there will always be a finite gap between you and the wall, such that a half way span will remain however small, and this process goes on forever. It therefore would take an infinite amount of time to reach the wall. But you don't have an infinite amount of time. So Zeno concluded that motion is an illusion. Nothing really moves, since logically it cannot.

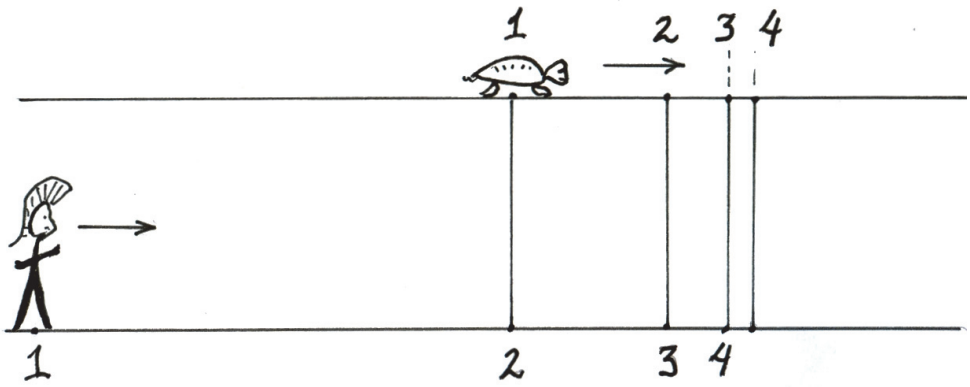

Figure 2.1 Zeno's paradox: Achilles & the Tortoise

Another of his paradoxes involved a race between Achilles and a tortoise, where the tortoise audaciously challenged Achilles to the race. This paradox is easily seen with a diagram (Figure 2.1). Achilles, being faster, gave the tortoise a head start (points 1 for each). As the race began and the tortoise moved forward from its starting point, Achilles too moved forward, being required to move to the tortoise's starting point (bottom 2). Their movements took a finite amount of time, during which the tortoise moved to its point (top 2); this was a much shorter distance than Achilles from his starting point, since he was much faster than the tortoise. Having gained on the tortoise, Achilles at his point 2 now had to reach his point 3, which also took a finite amount of time, so that the tortoise

moved a bit further to his point 3, an even smaller distance than the previous interval. Nonetheless Achilles still had not reached, let alone passed, the tortoise because he still had to reach his point 4, which took a finite amount of time, and meanwhile the tortoise moved forward a little bit further to its point 4, and….well, a pattern emerged such that Achilles could not win the race, since this process too went on infinitely. There were other examples from Zeno, but they were all variations on the same theme: motion is an illusion, since the courses of action required an infinite time span.

Because of the contraction between these deductions and our everyday experience of a reality in constant motion, these logical conundrums became known as paradoxes – Zeno's paradoxes. They puzzled many an ancient Greek thinker and they continue to confound us today. Just use the phrase "Zeno's paradoxes" as a computer search term and you may spend most the day (or more) reading popular and scholarly articles explaining or trying to resolve them. Or you may watch numerous YouTube videos visually reproducing them. Zeno's paradoxes bridge over millennia of time, from ancient Greece to today's cyberspace, just as the Second Commandment links up the ancient Israelites' smashing pagan effigies with the Taliban's assault on the Buddha idols.

Why did Zeno concoct these paradoxes? What motivated him to think of motion as an illusion? What was the intellectual context? To answer these questions we need to rewind time to a generation or so before Zeno, in the 6th century BCE.

From the time the ancient Israelites were exiled in Babylon to their release and return to Jerusalem and the eventual rebuilding of a Second Temple, not far away in the eastern Mediterranean region, within the colonies of Greek culture, there emerged like a burst of pristine light a flourishing of profound ideas among several thinkers, starting with Pythagoras, famous for a theorem about right triangles (that is, triangles with one 90-degree angle). Although he is famous today for that theorem, in fact, he was bothered by it – so much so, in fact, that he tried to hide what he found. Why? To understand his reticence in sharing what he discovered about right triangles, we must understand what it was he found – or better said, what he believed he found.

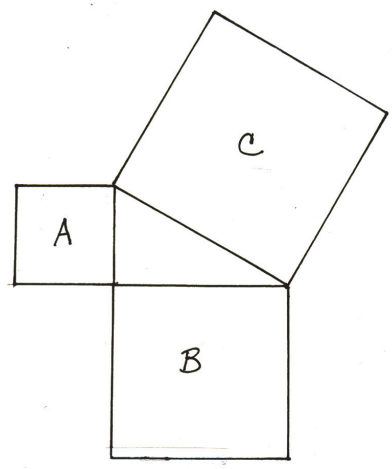

Figure 2.2 Pythagoras's theorem

Today his theorem is presented algebraically in textbooks this way: given a triangle with one right (90-degree) angle, the sum of the squares of the two sides is equal to the square of the hypotenuse. Algebra, however, began in India and came to the west by way of Islam (note the Arabic word, al-

gebra) much, much later in the Renaissance. The ancient Greeks, unaware of algebra, viewed the theorem geometrically; that is, there were really geometrical squares on all three sides of the triangle (Figure 2.2) and the sum of the areas of the ones on the sides added up to the area of the one on the hypotenuse (area **A** + area **B** = area **C**). Geometry and, of course, arithmetic (adding, subtracting, multiplying, and dividing) made up the two elements of Greek mathematics, and arithmetic consisted primarily of whole numbers and fractions (that is, there were no decimals). Much later, around 300 BCE, the corpus of Greek geometry was organized, summarized, and codified by Euclid in one work, called *The Elements [of Geometry],* and henceforth geometry became known through textbooks based on his work and was identified as what we still call Euclidean geometry.

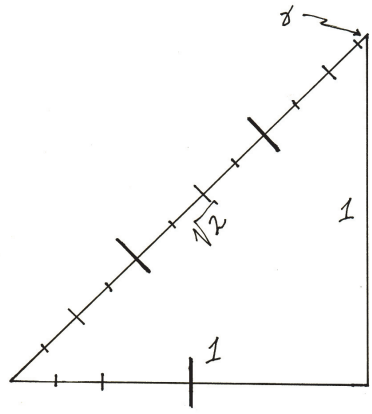

Figure 2.3 Right triangle with unit sides & hypotenuse of √2

Zeroing in on Pythagoras's discovery, consider this simple case: a right triangle with two equal sides of one unit value (called unity, for short). Today, looking at this algebraically, we have one-squared plus one-squared equals x-squared ($1^2 + 1^2 = x^2$); solving for x, we get the square root of two ($\sqrt{2}$) for the length of the hypotenuse (Figure 2.3). I now enter the number 2 into the calculator on my computer, and pressing the square root icon I get this number: 1.4142135623730950488016887242097. What the calculator does not tell me is that this number does not end with the last digit (7); instead it goes on, and on, and on…forever. Said otherwise, the number is an infinite decimal. How can that be? How can the size of the hypotenuse be an infinite decimal when it is clearly a number a little less than 1½? Put differently (since the Greeks had no decimals): how can this problem be expressed geometrically; that is, as Pythagoras saw it?

He discovered the problem this way. Return to the right triangle of equal unit sides (Figure 2.3) and try to divide either side into smaller units such that a multiple of these units fits *exactly* along the hypotenuse. For example, for a right triangle of sides 3 and 4, the hypotenuse is 5 units long, with all three numbers being whole numbers (algebraically: $3^2 + 4^2 = 5^2$). So for the right triangle of equal sides of one unit (1), how may whole number units must one side be divided into so that a whole number of these units fit along the hypotenuse? The task begins by dividing a side in half, in fourths, eighths, and so forth until reaching a unit that fits exactly along the hypotenuse in a whole number multiple. As I proceed with this process I find that units of the sides do not fit exactly as whole numbers into the hypotenuse for half, fourth, eighths, etc. But they do get smaller and closer as I continue along. For example, if I doggedly get as far as dividing the unit side into 7000 little units, I find that 9899 of these units will almost fit along the hypotenuse, except for one-half a unit left over. If I don't

quit, and I get as far as dividing the unit side into 25,000 units, there will be 35,355 units along the hypotenuse, but yet still one-third of a unit will remain. And so it goes. As Pythagoras found out: no matter how small a unit side is subdivided, there is no whole number of this small unit that fits exactly along the hypotenuse – there is always a smaller gap (**γ** in Figure 2.3; that is, the Greek letter small gamma) remaining. The process therefore continues to infinitely. Said another way: there is no whole number *ratio* between the sides and the hypotenuse of this right triangle, there is always some little **γ** left over, and that is why the square root of two is called irrational (no ratio; not rational). (Note that this is unlike the 3, 4, 5 right triangle, where there are the ratios 3/5 and 4/5.)

Today we would say this was the discovery of the first irrational number. For whatever deep psychological reason, Pythagoras was unable to fathom this process toward infinity; to him to it was unreasonable (irrational in both senses), since it defied his sense of order, which was a world composed of whole numbers only. One could almost say that he had it a phobia of infinity and that is why he tried to hide his discovery.

* * *

Any reader intimidated by mathematics may skip this short subsection, but be forewarned that we will need some of it in Chapter 8. Moreover, remember, math is fun!

Not all infinite decimals are irrational numbers. Using the definition above, that a rational number can be written as a ratio of two integers (whole numbers), say p/q, then the fraction 2/3 is a rational number; but written as a decimal, it is 0.666666…, an infinite decimal.

The criterion for distinguishing between rational and irrational infinite (non-terminating) decimals is that rational decimals *repeat* at some point along the route to infinity.

Consider this infinite decimal: 0.999999…. What is it as a fraction p/q?

Let X = 0.999999….

Multiplying by 10, we get:

10X = 9.999999…

Subtracting X: X = 0.999999…

Remainder: 9X = 9.

Therefore: X =1 or 1/1.

Thus the infinite decimal 0.999999… is the (rational) number 1.

Keeping the mathematical momentum going (for those of you who still have my attention): Consider X = 0.136363636….

Multiply by 100: 100X = 13.636363…

Subtract X: X = 0.136363636…

Remainder: 99X = 13.5

Therefore: X= 27/198 = 3/22, a rational number.

And so it goes: rational decimals *repeat* at some point along the route to infinity.

The square root of 2 is irrational, however; and irrational numbers are non-terminating and non-repeating decimals. This is the decimal way of expressing the geometrical problem of Pythagoras's triangle, when the sides cannot be divided into parts (say p) such that a whole number of them (say q) can fit along the hypotenuse, so arithmetically then p/q is not a whole number ratio, and thus √2 is not rational, by definition.

In sum, all rational numbers can be written as: (1) the ratio of two integers p/q, e.g., 1 =1/1, 12 = 12/1, etc.; or (2) an infinite and repeating decimal, e.g., 1 =0.99999…, 2/3 = 0.666666…, 3/22 = 0.1363636…, etc.

* * *

Pythagoras in his latter years was the leader of a cult in a Greek colony in southern Italy who, probably because of their unconventional behavior, were attacked and massacred by some nearby and less cultured tribes (some accounts say they were actually banished members of the cult itself). Nonetheless, Pythagoras's ideas lived on, by a follower or two who escaped the slaughter and who carried on the knowledge of irrational numbers to other Greeks. In the next generation of thinkers, the most important ones for this story are Heraclitus and Parmenides (the latter, Zeno's teacher) who, about the time the Second Temple was rising in Jerusalem, were putting forth their contrasting answers to the nature of our existence.

Unfortunately, our knowledge all of these early Greek thinkers (which includes Pythagoras and Zeno) is fragmented (literally), in that only fragments (sometimes a mere sentence or two) of their writings is all that we have (for Zeno we have nothing, except what Aristotle later tells us). Nonetheless, the fragments from Heraclitus and Parmenides are endlessly fascinating.

Heraclitus was from Ionia, on the Aegean coast of Asia Minor (today Efes, Turkey) and was called alternately the dark, weeping, or obscure philosopher. A source of this posture was surely his being overwhelmed by the flux, change, instability, and unrest that he perceived in life and nature. He was incapable of singling out any permanence in things. The famous aphorism from him, which was a metaphor for life, was that "we cannot step into the same river twice." He also saw fire as the symbol of this world view, with its constant motion; more literally he probably held fire to be the fundamental element of nature (as it later became one of the four elements).

In addition to viewing reality as a process – meaning that any sign of permanence was a figment of one's imagination, an illusion – Heraclitus was said to have put forward the concept of the "unity of opposites"(to be seen later, an important concept this story) and the first western thinker to do so, as far as we know. It is not straight away clear how a unity of opposites arises from an awareness of the flux of things, except perhaps that without anything being permanent there cannot be any opposites at all. Needless to say, Heraclitus put forth a provocative point of view that stimulated further questions and disputes.

His contemporary, Parmenides of Elea, challenged the monism of the flux of things, by recognizing that permanence is not illusionary. Ourselves, as we grow, change radically from infant to child to adult to old age, while our own being – our realization of a sense of self – remains constant. We are the same self we were at birth. An awareness of change is based on our empirical knowledge, our sense data. The perpetual or permanent, however, is derived from our reasoning, and reason is the more trustworthy source of knowledge according to Parmenides and many other ancient Greeks. Contrary to Heraclitus, the empirical is easily tainted by illusion, such as optical illusions. Reason properly executed leads to clear and sure knowledge. Heraclitus had it backwards.

Parmenides expressed his standpoint in a dense and abstract statement: "Only Being exists; Non-Being does not exist," which may be interpreted as meaning that there is no change, and hence all perceived flux is an illusion. Think about it: for motion to exist an object must move from one place to another; to do so the place it moves into must be empty. As a first step, the object may be opaque matter moving through air; then air moving through some further diffuse substance, such as the aether postulated by the ancient Greeks; but ultimately the aether must move into empty space. (An aside: the word *aether* is Latin, from the Greek, αιθηρ, meaning the upper air; not to be confused with ether, the organic compound $C_4H_{10}O$.) But empty space would be nothing, or Non-Being, which does not exist. Therefore, motion is impossible, and space is full and at rest. (There are ways around this, such as put forth later by Plato – that everything in the cosmos all move together – or from Plato's student, Aristotle – that empty space is not nothing, but a potential entity, which incidentally Einstein much later showed to be true; see coda to Chapter 6.) In short, Parmenides replaced the monism of