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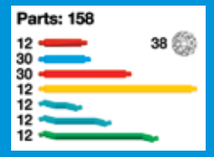
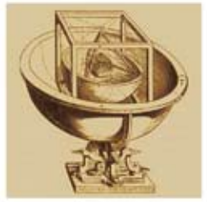
"The mind, once stretched by a new idea, never regains its original dimensions." –Oliver Wendell Holmes

Kepler's Obsession

***Kepler's Obsession* model designed by Dr. John Conway**

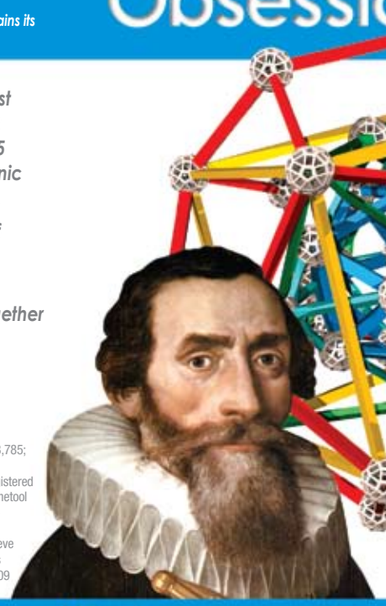




A deeply religious and rigorous scientist of the Renaissance, JOHANNES KEPLER believed the relationships among the 5 "perfect" 3-dimensional shapes (Platonic Solids) governed order in the universe.

Build a beautiful and elegant model of those relationships, and discover:

- *What inspired Kepler*
- *How the 5 "perfect" 3D shapes fit together*
- *Why Kepler's "mistake" laid the foundations of modern astronomy*
- *And how (in a sense) he might have been right all along!*



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START HERE! ## World in turmoil

Imagine a world in which short-sighted rulers use religious intolerance to create "endless war," bankrupting their people. Ancient practices like herbology, witchcraft and astrology continue to flourish amidst breathtaking advances in science and technology. Legal scholars wrestle with definitions of torture and its "proper" use, while new information technology is engulfing the masses in a tsunami of text and images. We're on the brink of a cultural revolution that will forever transform our place in the universe…

It's the dawn of the 17th century, and Johannes Kepler is about the lay the foundation of modern astrophysics.

In a life full of turmoil and personal tragedy, Kepler made significant contributions in fields diverse as astronomy, cosmology, optics, calculus, logarithms, and geometry. He also worked as an innkeeper's assistant, mapmaker, astrologer, calendar-maker… even as a lawyer (to save his mother from being burned as a witch!)[1]. He became Imperial Mathematician in Prague, though he wasn't always paid.[2]

Johannes Kepler was both profoundly religious and a rigorous scientist. Like Plato and Pythagorus, Kepler believed that God made the universe according to a plan, and he felt it was his Christian duty to understand God's works. His mathematical brilliance and love of truth made his work relevant to this day while raising the dander of the religious authorities in his day.

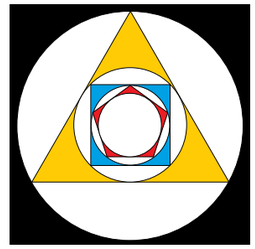
Me and my big mouth

After graduating from Maulbronn[3] Kepler won a scholarship to the University of Tübingen, and was expected to become a Lutheran pastor[4].

Mathematical sciences (arithmetic, geometry, astronomy and music) were required courses. Kepler's astronomy professor publicly taught that the earth was the center of the universe (Ptolmy) but privately believed in Copernicus's sun-centered version. Kepler "got it" almost instantly and defended Copernicus in a public debate, ensuring he would never get a job in Tübingen—Martin Luther himself rejected Copernicus's scheme, using the Bible to "disprove" it.

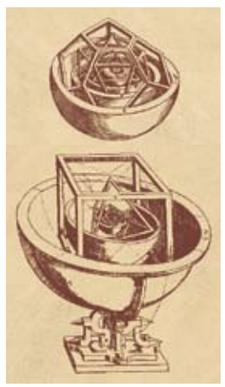
The flash of light

Kepler got a job 677 km (421 miles) away, as astronomy professor in Graz (now in Austria). While teaching math he was taken by a drawing of concentric circles inscribed in and circumscribing a triangle, believing it might be the "key to the universe" (i.e., how God determined the distances between the orbits of the planets). He tested his theory, but the ratios were wrong.



Kepler's first attempt to geometrically define the distances between planetary orbits (with color-coding informed Zometool).

Then he considered the problem in 3 dimensions. The circles of the planets' orbits became spheres, and the shapes separating them became the 5 regular solids. It was an elegant solution: there were only 6 known planets and the Greeks had proved there are only 5 regular polyhedra. The model's beauty and simplicity could only be God at work.



Kepler tested his theory using the planetary orbits deduced by Copernicus, and the error was less than 10% (spectacular for a cosmological model even today). He published his theory in the modestly titled Mysterium Cosmographicum (*The Secret of the Universe*), blamed the discrepancies on errors in Copernicus's data... and sought better data.

Tycho (not a toy)

Rich, fat and noseless[5], Tycho Brahe kept the most meticulous astronomical data on the planet. When Kepler was kicked out of Graz for being a Lutheran[6], Tycho invited him to be his assistant in Prague. Tycho jealously guarded his own data, which he hoped would prove that the sun rotates around the earth while all the other planets go around the sun. He set Kepler to work on Mars's orbit—embodying his toughest and richest data—because (as Kepler discovered) it's most elliptical.

A year later, Tycho died of overindulgence. Kepler had said Tycho was "superlatively rich, but knows not how use it…one must try to wrest his riches [i.e., his data] from him." Now he did just that, as Tycho's heirs rushed to liquidate the estate. (Did he inherit his dad's mercenary slant?)[7]

War with Mars

Kepler had bet Tycho he could solve Mars's orbit in eight days; in fact, his "war with Mars" took him 8 years and a thousand pages of hand-written calculations. But it ultimately yielded his 3 Laws of Planetary motion, which form the basis of modern astrophysics.

Kepler's Laws

1. Planets move in elliptical orbits with the sun at one focus.

2. In their orbit around the sun, planets sweep out equal areas in equal times.

3. The squares of the times to complete one orbit are proportional to the cubes of the average distance from the sun.

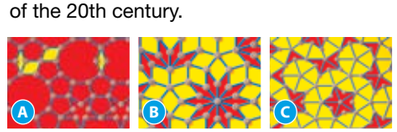
He published his first two laws in Astronomia nova (*New Astronomy*) in 1609, but didn't articulate the 3rd until his 2nd magnum opus, Harmonices mundi (*Music of the Spheres*) was already on press in 1619. This contained a more elaborate model of the cosmos, and a goldmine of 2- and 3-D geometry: a proof that there are only 13 Archimedean solids[8], 2 new non-convex regular polyhedra, and the first orderly treatment of mathematical tilings.

Illustration of Kepler's 2nd Law: a planet sweeps out equal areas in equal times (image exaggerates the elipse's eccentricity.)

2 non-convex regular polyhedra discovered by Kepler and published in Harmonices mundi in 1619.

Harmonices mundi is a brilliant and daring 17th century "Theory of Everything[9]" in which Kepler explains the math, but also mechanics and "music" of the universe.[10]

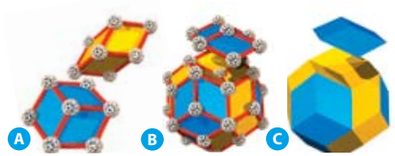
One of Kepler's most interesting tilings is based on the number 5 (the "red" plane in Zometool). Assembled from pentagons, decagons and stars, it doesn't repeat indefinitely nor articulate matching rules, but it heralded Richert and Penrose tilings of the 20th century.



Kepler tiling (A) with fat and skinny Richert diamonds in yellow, Richert tiling (B) and Penrose tiling (C)

Kepler Blocks

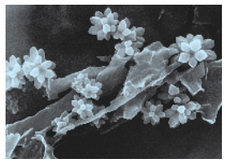
Kepler also discovered the rhombic triacontahedron and its sub-units (Kepler blocks), which are 3-dimensional cousins of Richert tilings. While Richert's tiles are 2 types of "squashed" squares (parallelograms), the triacontahedron can be built up from 2 types of "squashed" cubes (parallelepipeds), and Kepler blocks will also fill space according to matching rules just as Penrose tiles can cover a plane surface quasiperiodically.



Kepler blocks (A), assembled to form a rhombic triacontahedron (B), Zometool parts removed (C)

Kepler blocks made a startling reappearance in the 20th century with Daniel Shechtman's discovery of quasicrystals. At the time, crystalography was considered a "closed" science and 5-fold crystals were "known" to be impossible.

Schectman's discovery incited a "Copernican revolution"[11] in the materials sciences. We hope J.K. is chuckling in heaven.



Quasicrystal photo by Dr. H.U. Nissen. The "apple blossoms" approximate Kepler blocks.

Endnotes

[1] *Katharina Kepler was an innkeeper who collected herbs and made potions she believed had magical powers. At age 74, when she was tried as a witch, Johannes acted as her lawyer and eventually won her release at least partly because of ethical objections due to the authorities' failure to follow correct legal procedures in the use of torture.*

[2] *By the end of his life, Kepler was owed some 12,000 gulden (about $100,000 at current silver prices) by various rulers who were perpetually broke. He died while trying to collect a debt.*

[3] *Maulbronn was haunted by the ill-famed Dr. Faustus a half-century earlier*

[4] *The system was funded by the Dukes of Württemburg to supply educated clergy to defend the faith in religious battles raging between Catholics and Protestants.*

[5] *Tycho Brahe lost a chunk of his nose in a duel with another danish noble man, Manderup Parsberg.*

[6] *Ironically, Kepler was excommunicated from the Lutheran Church in 1612, a wound from which he never recovered.*

[7] *Heinrich Kepler was a soldier of fortune: "a man viscous, inflexible, quarrelsome and doomed to a bad end." He abandoned the family when Johannes was 5 and presumably died in battle.*

[8] *12 of the 13 Archimedean solids can be built with Zometool (although they require blue green lines, which we don't consider part of the Zome system). Number 13, the snub dodecahedron, can be approximated.*

[9] *A. Garrett Lisi's 21st century Exceptionally Simple Theory of Everthing is based on an 8-dimensional space (E8) that can also be modeled using Zometool.*

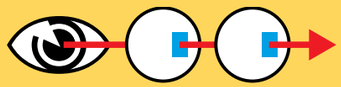
[10] *See quote from Harmonices Mundi in the inset on the other side*

[11] *D. Mermin, Physical Review Letters 68, 1172 (1992)*

ZOMETOOL RULES!

1 *If it works, it works perfectly.*

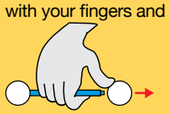
…and if it doesn't work, it doesn't work at all. Don't force Zometool components. You can bend a strut to fit it into a tight spot, but struts in finished models are always straight, never under tension.



Hint: you can tell which strut fits between two balls in a model by lining up the balls and looking through the holes. The holes show you the shape of the strut that fits!

2 *Don't break it apart; take it apart!*

Take Zometool models apart by grasping a strut with your fingers and pushing the ball straight off with your thumb. Twisting balls, pulling models apart or crushing them can cause parts to break!*



3 *Leave the place cleaner than you found it.*

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Zometool Kepler's Obsession Project — Dr. John Conway, concept; Dr. Scott Vorthmann, vZome software for images; Anni Wildung, graphic design; Paul Hildebrandt, copywriting and project management. Contact paulh@zometool.com. Based on the 31-zone system discovered by Steve Baer, Zomeworks Corp., USA. © 2009 Zometool Inc.

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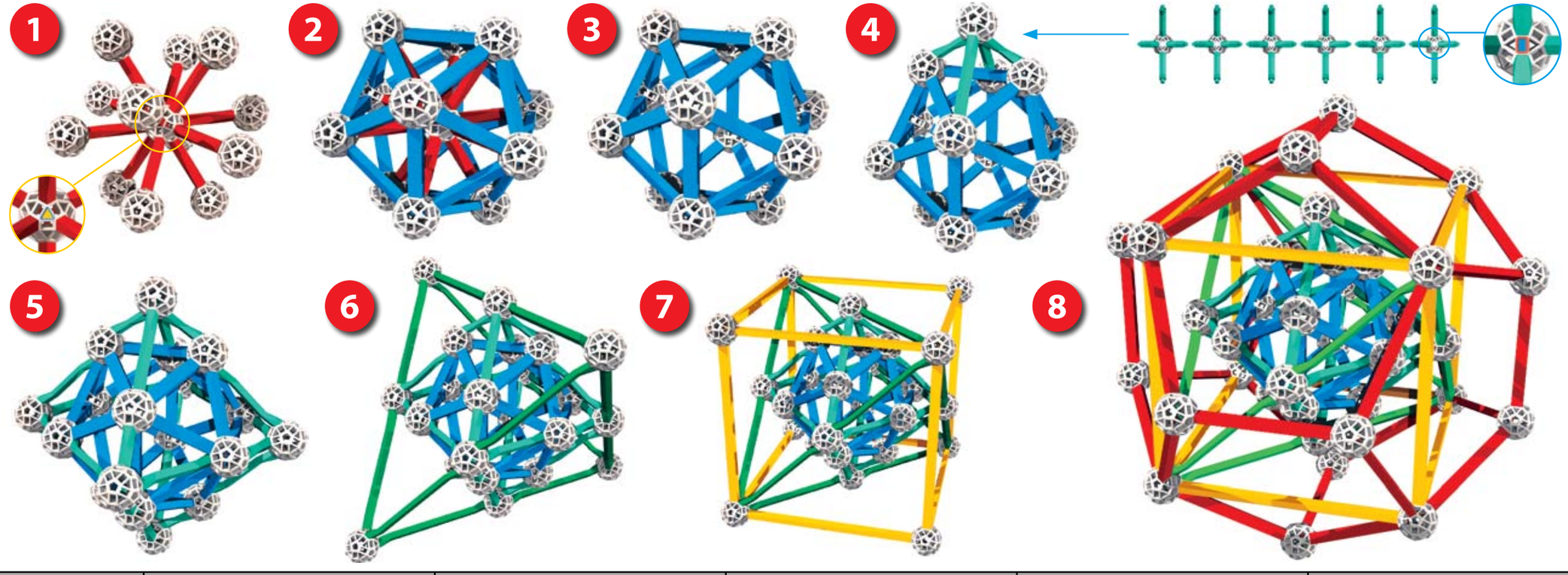
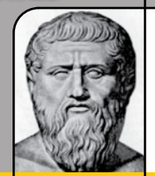
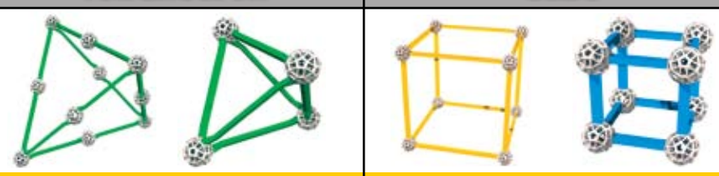
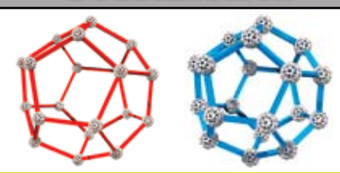
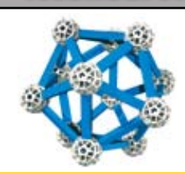
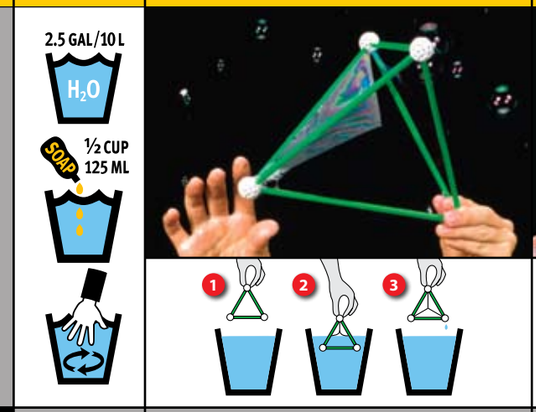
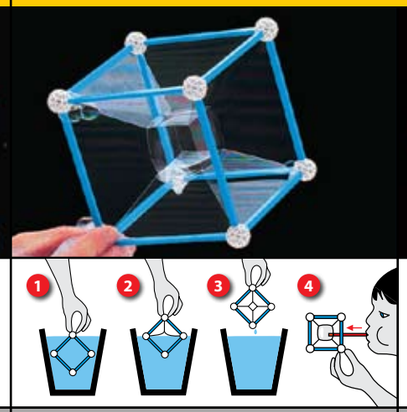
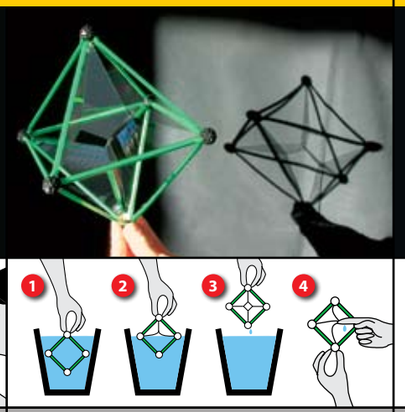
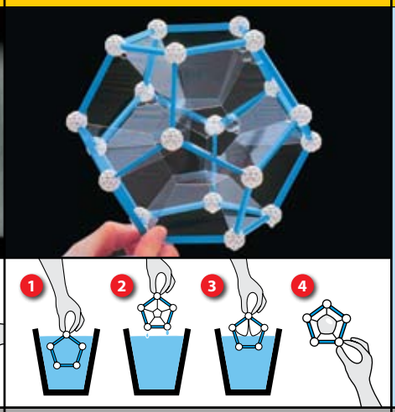
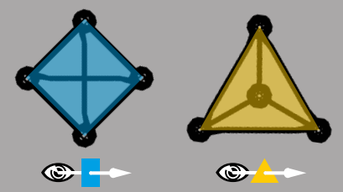
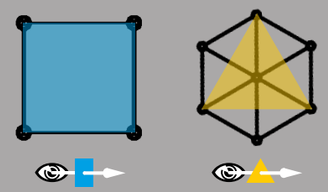
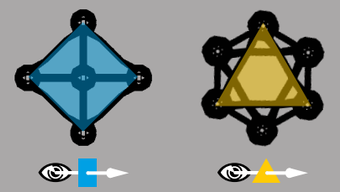
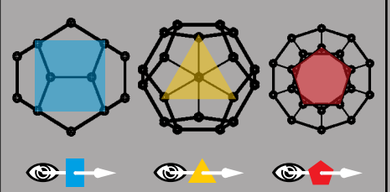
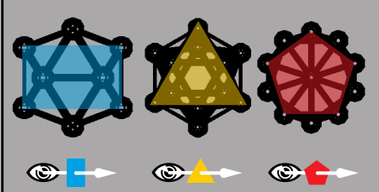


Solids	Tetrahedron	Cube	Octahedron	Dodecahedron	Icoshedron
Plato's					
Euler	F+V=E+2*	4+4=6+2	6+8=12+2	8+6=12+2	12+20=30+2	20+12=30+2
Bubbles					
Shadows					

*Euler's formula states for any convex polyhedron, the number of vertices and faces together is exactly two more than the number of edges. Try it!

1. Place strut in any hole.
2. Point strut at the sun.
3. Use board at 90° to light rays.

> *"The planetary motions are thus nothing else than a continuing, polyphonic music (perceived by the mind, not the ear); a music, which progresses through dissonant tensions, as if by syncopations and cadences (as Man uses these, in imitation of those natural dissonances), toward certain predetermined points of completion; and by doing so, sets its various marks onto the immeasurable expanse of time."*
>
> – Johannes Kepler, Harmonices mundi, 1619