
art and science at play

# ZOMETOOL®

## Kepler's Kosmos

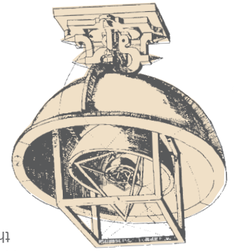
At the beginning of the 17th. century, the world was in turmoil. The Thirty Years' War was deminating Germany and the Netherlands were embroiled in the struggle for independance from Spain; ancient practices such as herbology, witchcraft and astrology continued to flourish amidst breathtaking advances in science and technology. Hugo Grotius' book, Das freie Meer (The Freedom of the Seas) - the basis of our current conception of civil-rights - was banned by the Pope immediately after publication, whilst in England Shakespeare's Sonnettes were being received with great acclaim.

In March 1609 in Prag, Johannes Kepler, mathematician to the Holy Roman Emporer Rudolf II, presented his master with a heavy book. His work, **Astronomia Nova**, subtitled Physica Coelestis, (Physics of the Heavens), marked the beginning of a new era.

Despite a life filled with trouble and personal tragedy, Kepler's contribution in many very different fields, such as astronomy, cosmology, optics, arithmetic and geometry, is significant.


above: Kepler's illustrations of the Platonic Solids from the **Mysterium Cosmographicum**, 1596:
**Cube** - earth, **Tetrahedron** - fire, **Dodecahedron** - universum, **Icosahedron** - water, **Octahedron** - air.
far left: quill illustration of the moon, from Sidereus Nuncius, Galileo Galilei, 1610.

Kepler was born in Weil der Stadt; a sickly child, whose sight was marred by smallpox at an early age. He worked at his mother's inn, drew maps and attended a school for latin and the grammar school in Maulbronn. He was a gifted child and graduated from his theology course at the University of Tübingen at the early age of 20. During this time, he studied Copernicus' vision of the world and, at 23, renounced his plan to become a protestant priest in order to take up a professorship for mathematics at Graz. He became more and more interested in the work of Copernicus and realised that he had stumbled upon an untapped treasure. Kepler began searching for a system behind the relationships of the distances between the planets and the sun, hoping to discover a "construction plan of the world". He sought harmony and intrinsic coherence, believing that God's works, like our architecture, must be subject to rules and regulations. He hoped to find the solution in geometry.



Kepler's theory stated that if a particular regular polyhedron were to by placed within the orbit of a planet, the sphere which exactly surrounded this solid would then, by definition, describe the orbit of the next planet. Kepler took the orbit of the earth as the determining factor for all subsequent orbits. It was an elegant solution: at that time, there were only six known planets and the Greeks had discovered that there are only five polyhedrons. Kepler tested this theory, using Copernicus' calculations as a basis and the result showed a discrepancy of less than 10%... Even by today's standards, a quite stunning success.

Kepler's cosmological theory, later published under the title **Mysterium Cosmographicum** (The Secret of the Universe) was born.

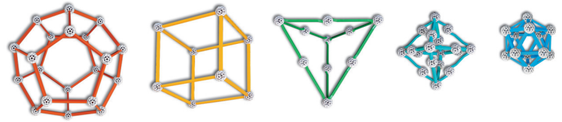

### Kepler's Kosmos

***It is the beginning of a new era.***

**Kepler in Prag**

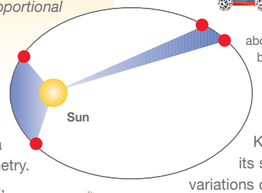
The Danish astrologer, Tycho Brahe, invited Kepler to work with him in Prag. It is probable that Brahe was interested in Kepler's mathematical skills, hoping that these would complement his own precise observations. Following Brahe's death a year later, the Holy Roman Emporer Rudolf II, a Habsburger, appointed Kepler to be his court mathematician in Prag. Kepler therefore "inherited" Brahe's extensive works, with which he hoped to improve his own earlier theories. The measurements did not conform and he was forced to abandon his attempt. He began work on an astrological system which was not based on the planetary orbits. In 1609, Kepler published **Astronomia Nova**, a book which contains the first and second of Kepler's Laws.

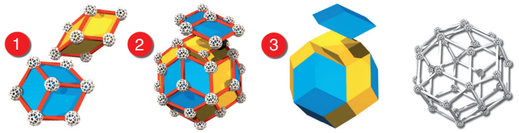
***The flash of light:*** *Kepler believed that God had given him a sign and that he had discovered the „key to the universe". Kepler summised that the numerical ratio between the orbits of neighbouring planets would be similar to the sphere radius of the regular multi-sided solids (polyhedrons) - ie: that of the inscribed sphere to the circumscribed sphere.*



above: Zometool models of the five Platonic Solids, corresponding to Kepler's vision of the universe:
**Icosahedron, Octahedron, Tetrahedron, Cube** und **Dodecahedron**.

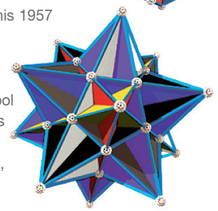
***Kepler's Laws of Planetary Motion:***
***1.*** *The orbit of every planet is an ellipse with the sun at one focus.*
***2.*** *A line joining a planet and the sun sweeps out equal areas during equal intervals of time.*
***3.*** *The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.*



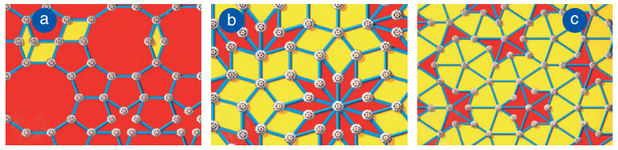

above: 1 **Kepler blocks**, 2 + 3 arranged to form a rhombic triacontahedron.
below: **Tiling**, a Kepler, with large and small Richart diamonds (yellow), b Richart and c Penrose.

Johannes Kepler described his third theory in **Harmonicus Mundi** (The Harmony of the World), which he published in 1619. It contains a more precise model of the cosmos and is a treasure trove of both 2-dimensional and 3-dimensional geometry. He proved that there are 13 half-regular Archimedean solids, discovered two new non-convex polyhedrons and compiled the first systematic documentation of mathematical tessellations. **Harmonicus Mundi** is a brilliant and daring "Theory of Everything", in which Kepler explains not only the mathematics, but also the mechanics and the "music" of the universe. Paul Hindemith created a musical monument to Kepler with his 1957 composition, Harmonie der Welt.



Kepler's further works include the study of the hexagonal structure of snowflakes (see Zometool kit **Ice Crystals and Stars**) and of tessellations with regular pentagons (Zometool's red plane). His investigations into flat tessellations with pentagons, decagons and stars heralded the tilings of Clark Richert and Sir Roger Penrose in the 20th century.

Kepler also discovered the rhombic triacontahedron and its sub-units (Kepler blocks), which are a 3-dimensional variations of Richert tilings. While Richert's tiles are two types of "squashed" squares (parallelograms), the triacontahedron can be constructed with two types of "squashed" cubes (parallelepipeds). Kepler blocks will fill space according to matching rules, just as Penrose tiles can cover a plane surface quasiperiodically. Kepler blocks have experienced an exciting revival during the 20th century, with Dan Schechtman's discovery of quasicrystals, which prompted a "Copernican revolution" in the material sciences.

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# ZOMETOOL®

The components of Kepler's Kosmos are naturally compatible with all other Zometool kits.


„**Hyperdo**", „**design 5**" and „**Creator 3**": just a small taste of the many possibilities in the extensive and versatile Zometool Universum.

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