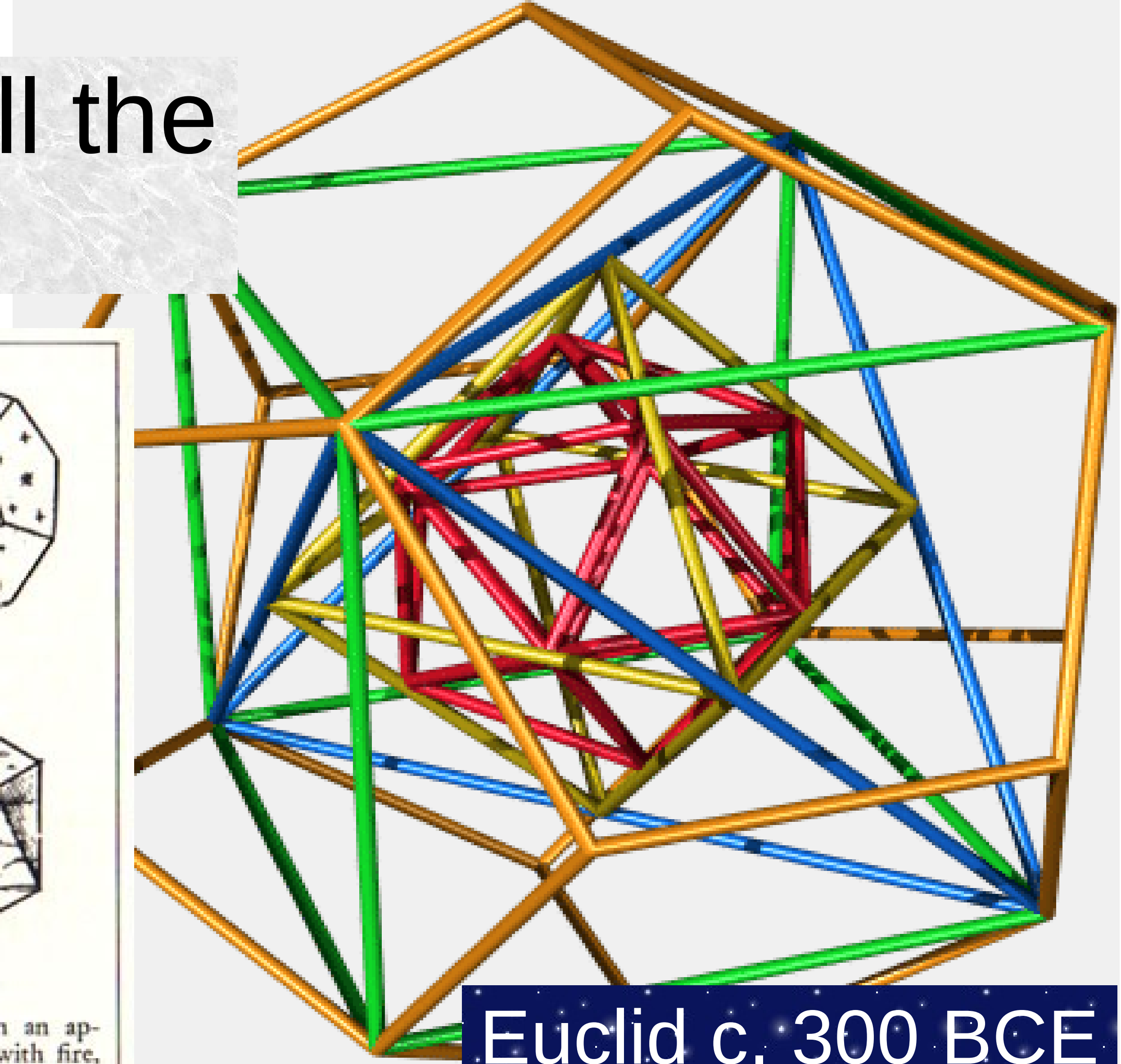
What's stuff made of?

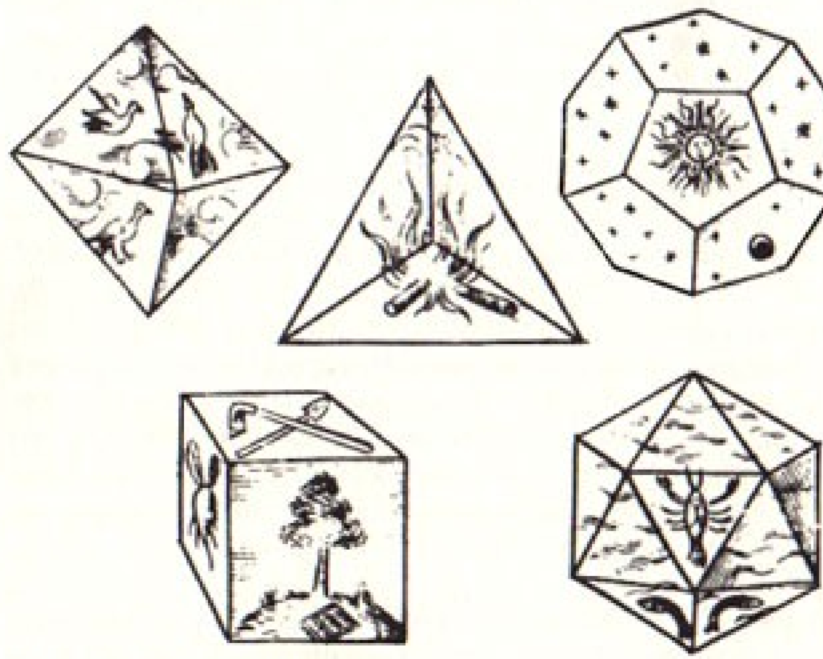
"I would rather understand just one cause than be king of Persia"

Democritus c. 460 – 370 BC

But what are all the atoms?



Euclid c. 300 BCE

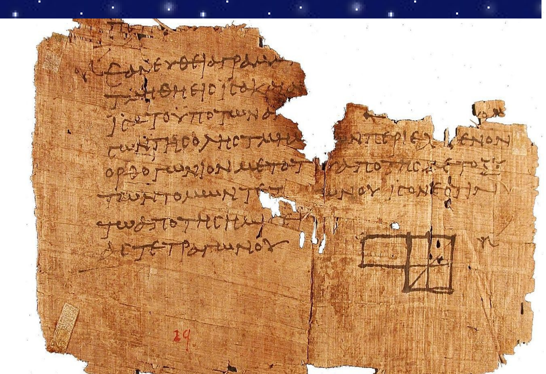


The five regular solids

Each of the five regular solids is pictorially identified with an appropriate element: the octohedron with air, the tetrahedron with fire, the cube with earth, and the icosahedron with water. The dodecahedron represents the universe at large, and therefore it displays the sun, the moon, and the stars of heaven.

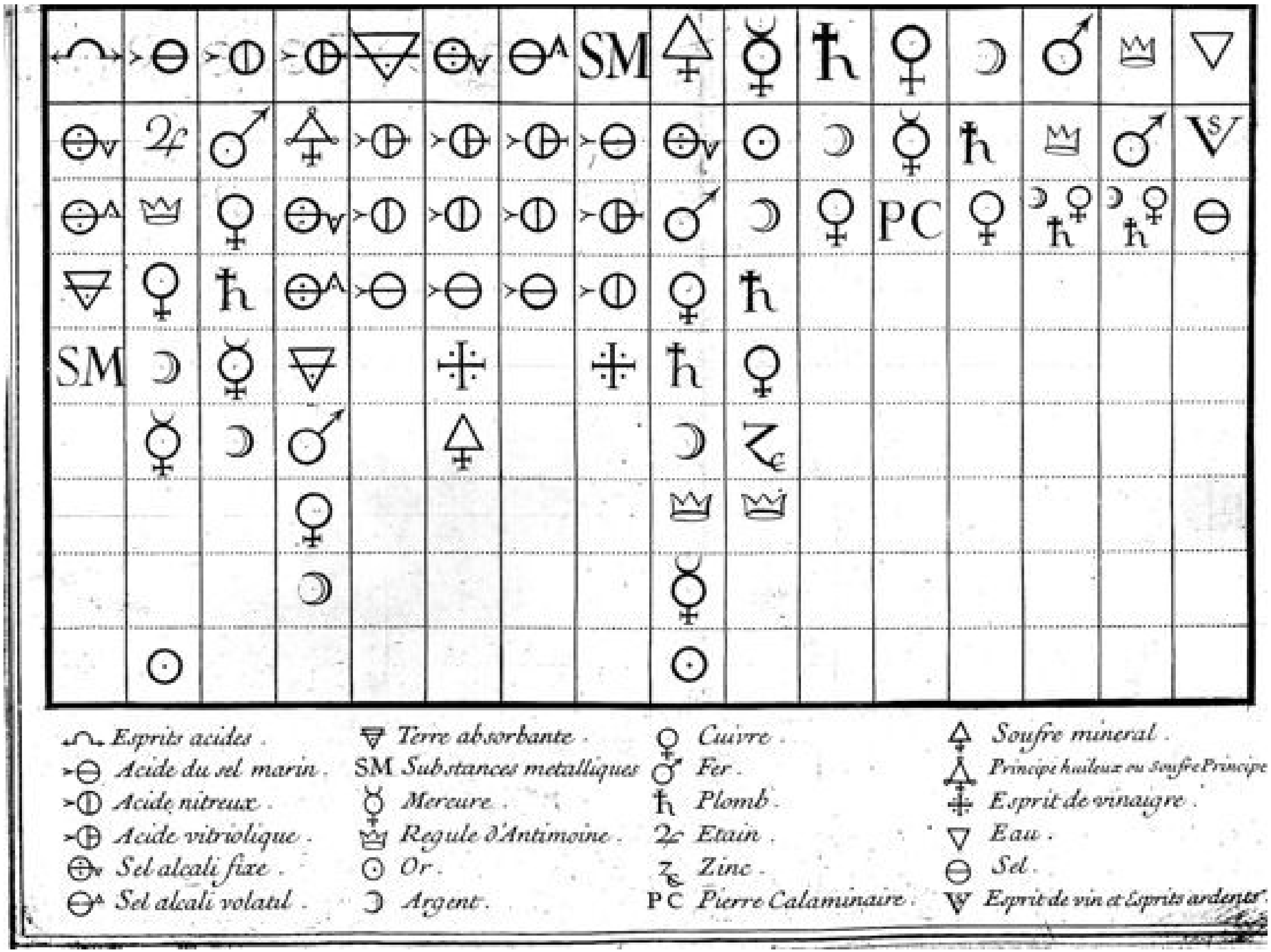
Johann Kepler, *Harmonices mundi libri V* (Linz, 1619), p. 52.

“Nature uses as little as possible of anything.”




Time
skip

Organize them by “affinity”?



Oil has affinity for:
Alkali salts
Iron
Copper
Lead
Silver
Antimony
Spirit of Vinegar
Gold

Etienne Geoffroy 1718

"The elements,
if arranged according to the atomic weight,
exhibit an apparent periodicity of properties"

Dmitri Mendeleev
1834-1907

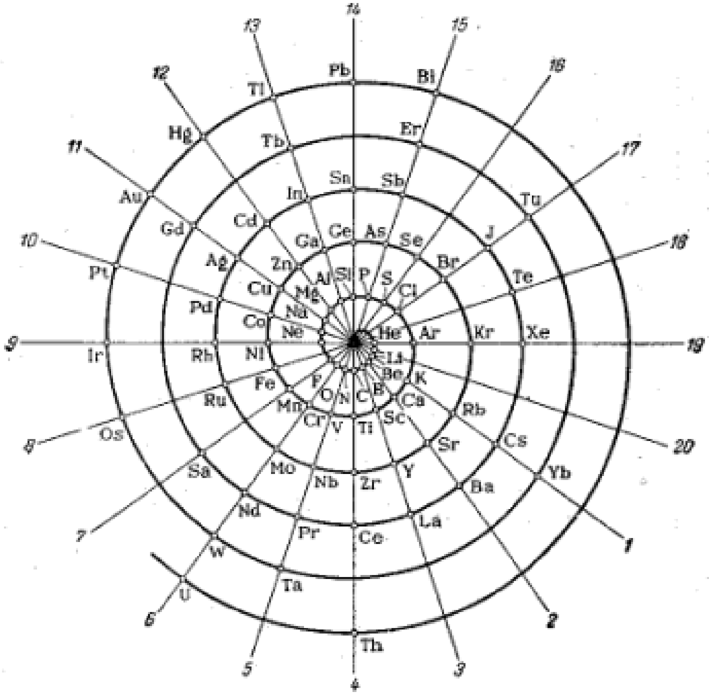
ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

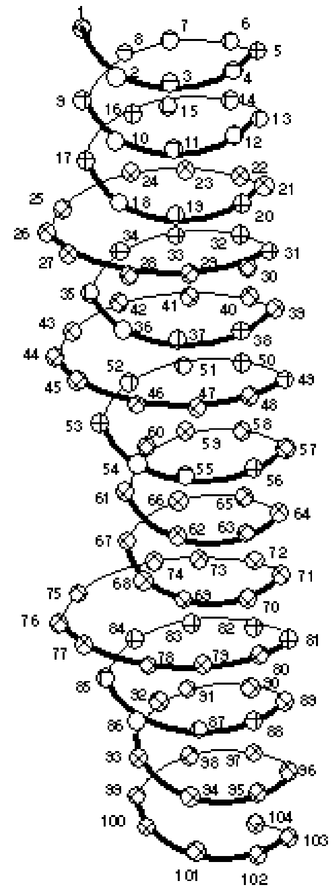
			Ti=50	Zr=90	?=180.
			V=51	Nb=94	Ta=182.
			Cr=52	Mo=96	W=186.
			Mn=55	Rh=104,4	Pt=197,4.
			Fe=56	Rn=104,4	Ir=198.
			Ni=Co=59	Pl=106,6	Os=199.
H=1			Cu=63,4	Ag=108	Hg=200.
	Be=9,4	Mg=24	Zn=65,2	Cd=112	
	B=11	Al=27,4	?=68	Ur=116	Au=197?
	C=12	Si=28	?=70	Sn=118	
	N=14	P=31	As=75	Sb=122	Bi=210?
	O=16	S=32	Se=79,4	Te=128?	
	F=19	Cl=35,5	Br=80	I=127	
Li=7	Na=23	K=39	Rb=85,4	Cs=133	Tl=204.
		Ca=40	Sr=87,6	Ba=137	Pb=207.
		?=45	Ce=92		
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75,6	Th=118?		

Д. Менделѣевъ

Where does the periodicity come from?



a



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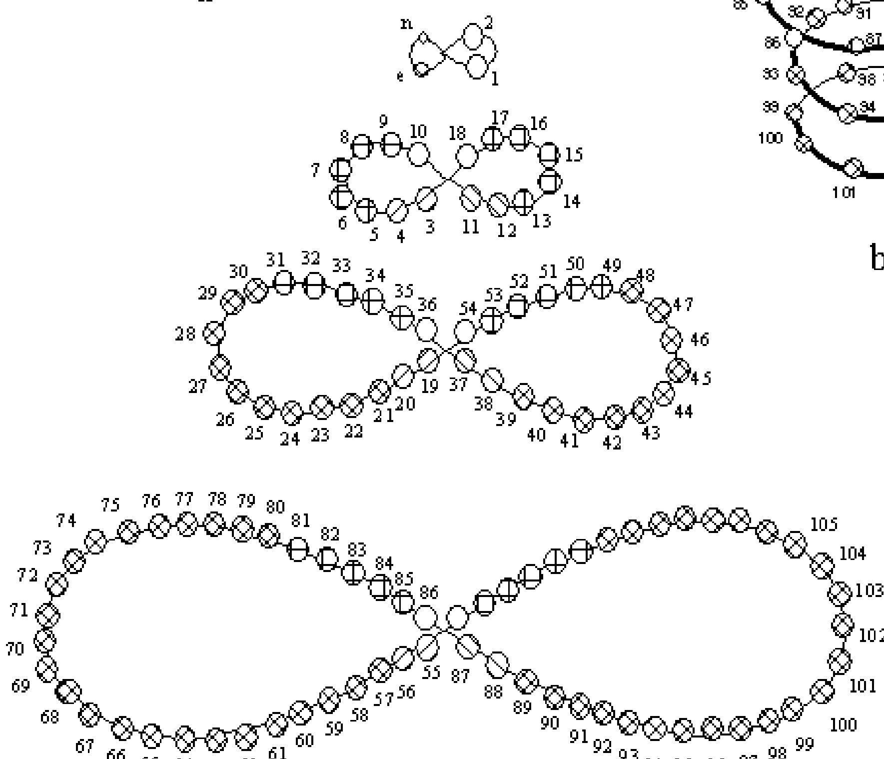

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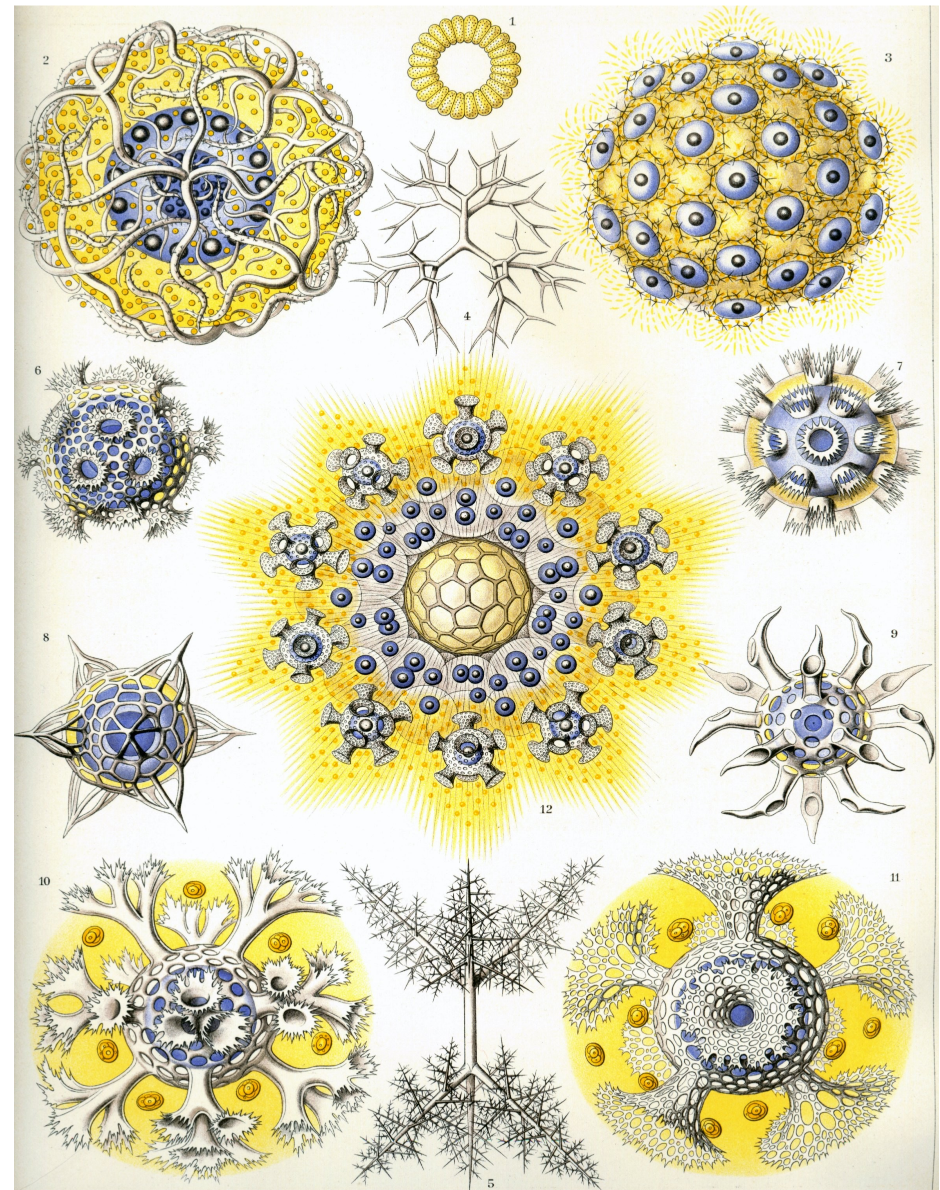
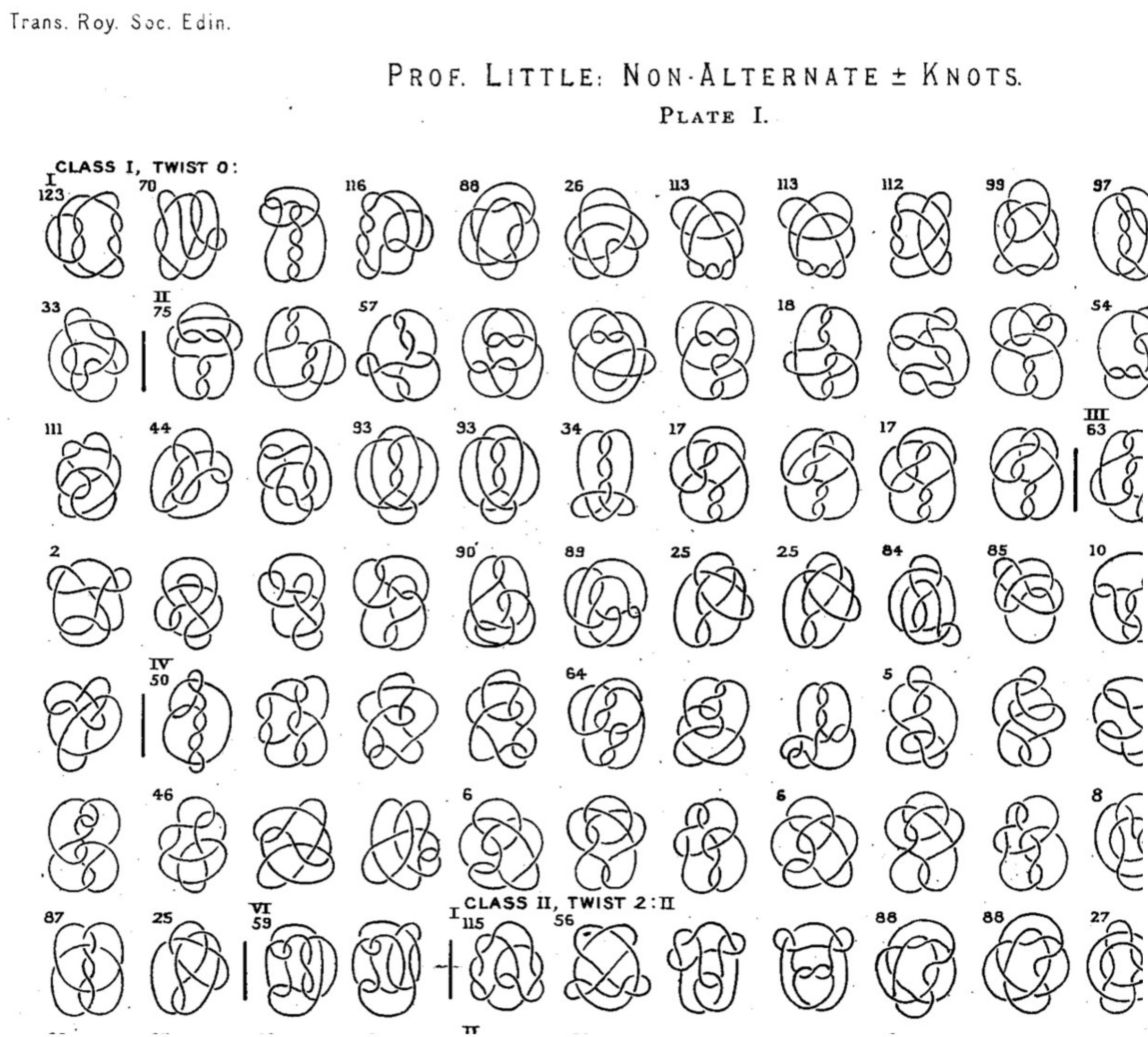
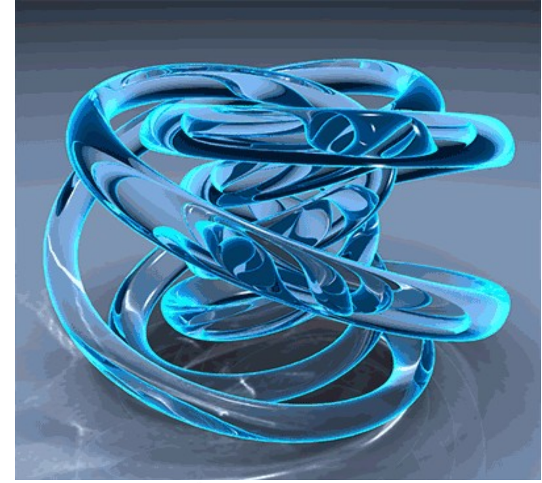
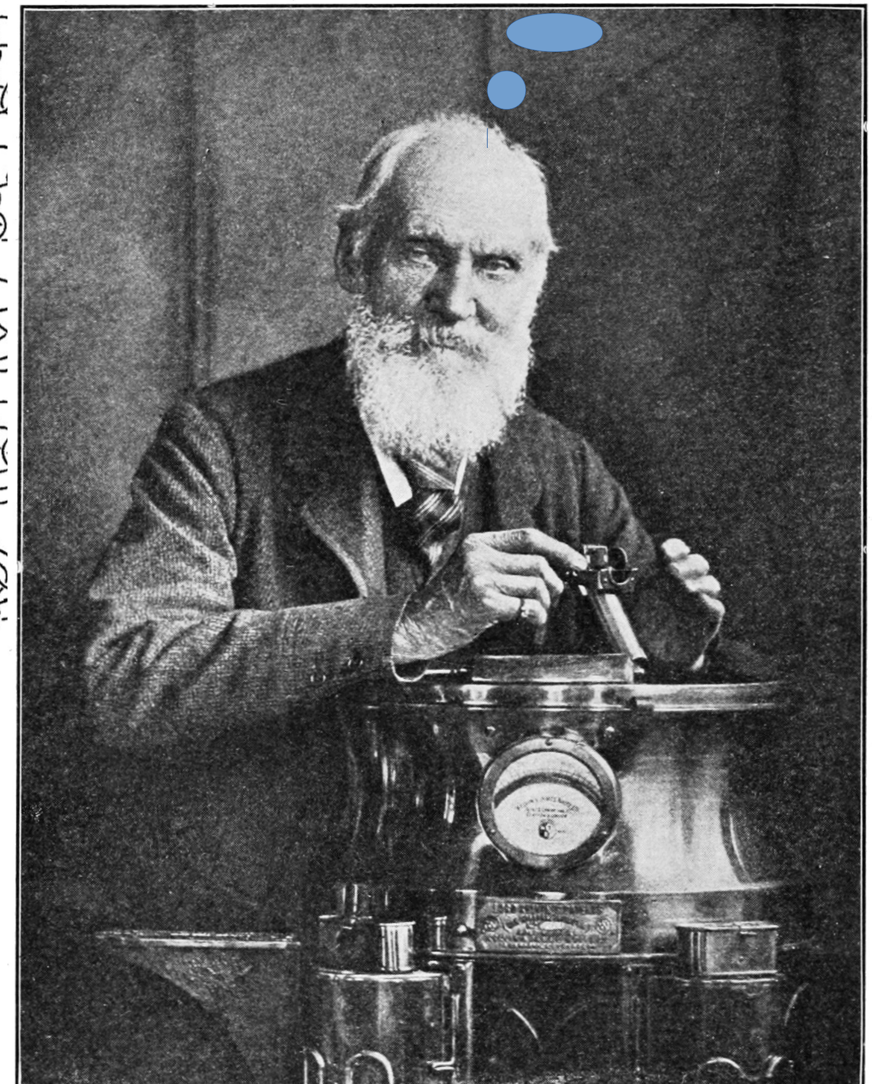








"Knots are cool. Atoms must be tiny knots!"

Lord Kelvin 1824-1907

Right Answer?

SYMMETRY

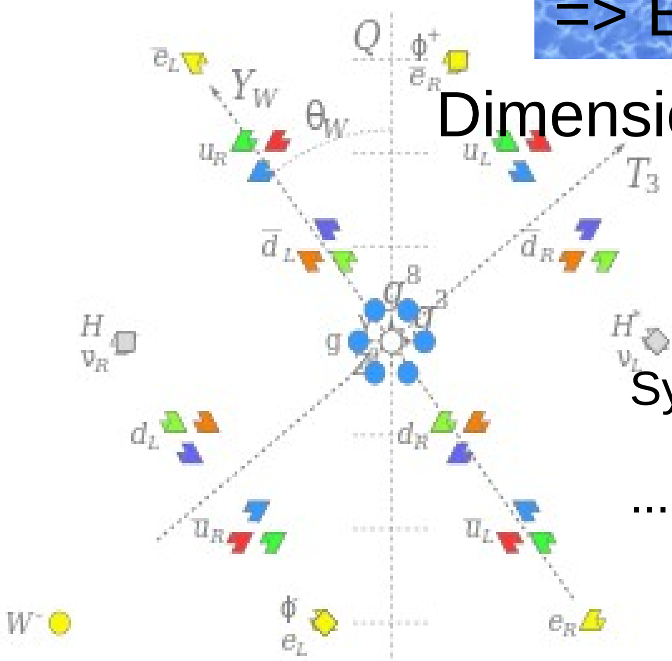
Emmy Noether 1882-1935

An atom with point-like nucleus has a 3-dimensional rotation symmetry

=> Electron wavefunction must *also* be symmetrical

Dimensions of representations are 2, 6, 10, 14 ...

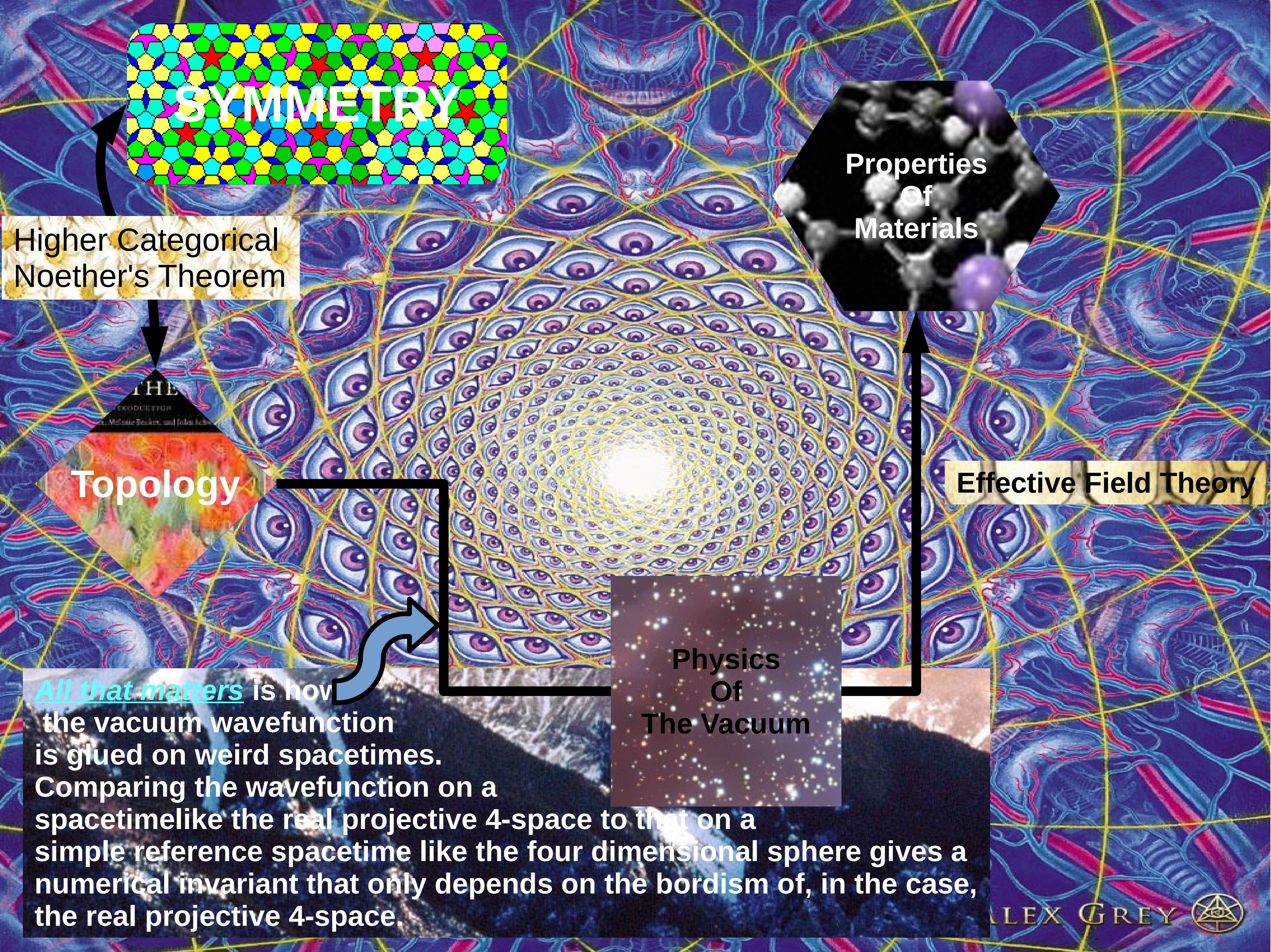
These are the s, p, d, f type orbitals



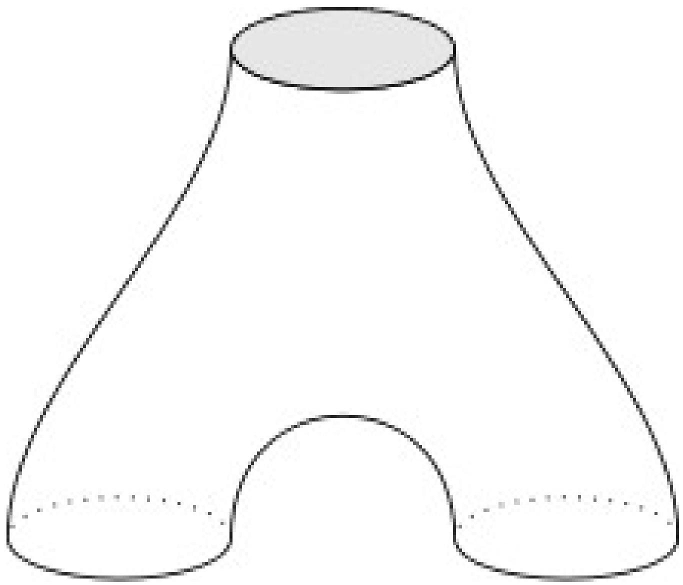
Symmetry also allows us to organize the subatomic particles!

...but their symmetry U(1) x SU(2) x SU(3) is a story for another time

In a way, the ancient Greeks were almost right!


SYMMETRY
Higher Categorical Noether's Theorem
Topology
Properties Of Materials
Effective Field Theory
Physics Of The Vacuum
All that matters is how the vacuum wavefunction is glued on weird spacetimes.
Comparing the wavefunction on a spacetimelike the real projective 4-space to that on a simple reference spacetime like the four dimensional sphere gives a numerical invariant that only depends on the bordism of, in the case, the real projective 4-space.
ALEX GREY

Bordism is an equivalence relation on manifolds

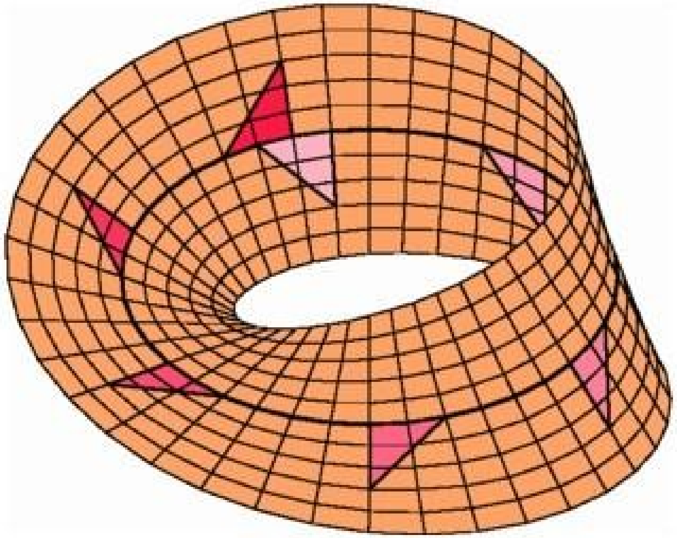


One circle is bordant to two circles

One point is **not** bordant to two points

A Moebius strip glued to a disc is not bordant to a sphere
Hint: Euler characteristic mod 2 is preserved by bordism

It is impossible to classify manifolds, but in many cases with certain geometric structures on our spacetimes, the bordism has been computed.



“Fermionic Symmetry Protected Topological Phases and Cobordisms”

Table 1: *Spin* and *Pin*$^{\pm}$ Bordism Groups

$d = D+1$	$\Omega_d^{Spin}(pt)$	$\Omega_d^{Pin^-}(pt)$	$\Omega_d^{Pin^+}(pt)$	$\Omega_d^{Spin}(B\mathbb{Z}_2)$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0	$\mathbb{Z}_2^2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_8$	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$
3	0	0	$\mathbb{Z}_2$	$\mathbb{Z}_8$
4	$\mathbb{Z}$	0	$\mathbb{Z}_{16}$	$\mathbb{Z}$
5	0	0	0	0
6	0	$\mathbb{Z}_{16}$	0	0
7	0	0	0	$\mathbb{Z}_{16}$
8	$\mathbb{Z}^2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2 \times \mathbb{Z}_{32}$	$\mathbb{Z}^2$
9	$\mathbb{Z}_2^2$	$\mathbb{Z}_2^2$	0	$\mathbb{Z}_2^4$
10	$\mathbb{Z}_2^2 \times \mathbb{Z}$	$\mathbb{Z}_2 \times \mathbb{Z}_8 \times \mathbb{Z}_{128}$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^4 \times \mathbb{Z}$

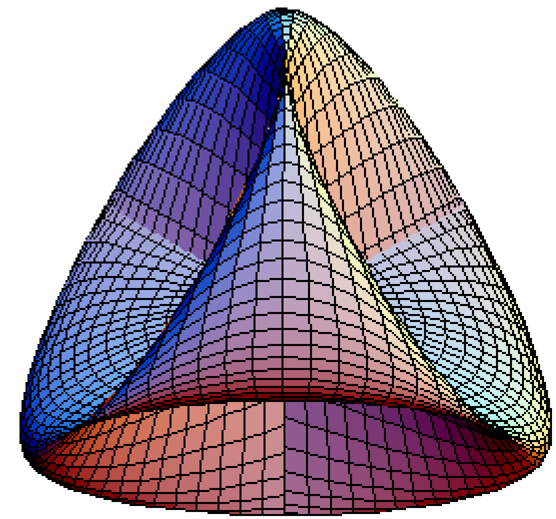


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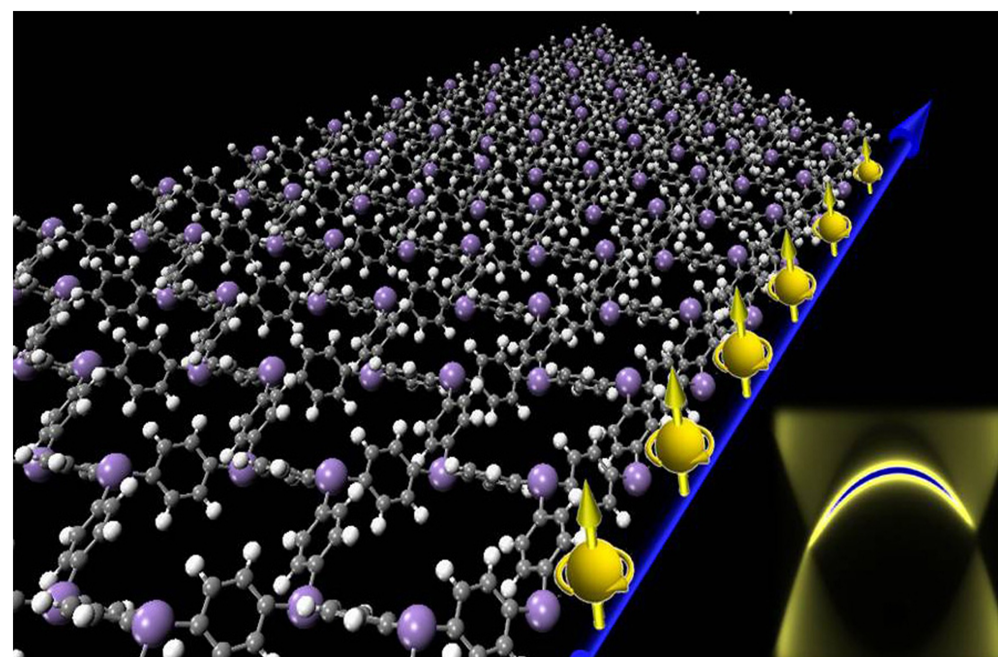
Table 2: Interacting Fermionic SPT Phases

$d = D+1$	no symmetry	$T^2 = 1$	$T^2 = (-1)^F$	unitary $\mathbb{Z}_2$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0	$\mathbb{Z}_2^2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_8$	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$
3	$\mathbb{Z}$	0	$\mathbb{Z}_2$	$\mathbb{Z}_8 \times \mathbb{Z}$
4	0	0	$\mathbb{Z}_{16}$	0
5	0	0	0	0
6	0	$\mathbb{Z}_{16}$	0	0
7	$\mathbb{Z}^2$	0	0	$\mathbb{Z}_{16} \times \mathbb{Z}^2$
8	0	$\mathbb{Z}_2^2$	$\mathbb{Z}_2 \times \mathbb{Z}_{32}$	0
9	$\mathbb{Z}_2^2$	$\mathbb{Z}_2^2$	0	$\mathbb{Z}_2^4$
10	$\mathbb{Z}_2^2$	$\mathbb{Z}_2 \times \mathbb{Z}_8 \times \mathbb{Z}_{128}$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^4$

7



Kelvin's dream realized?


Thank Y'all