Introduction to Physical Geology (GEOL 1)

Dr. Ryan J. McCarty

Science and Learning

How to learn

Learning new things requires some work

Best way to **learn new things** is build on things **you already know**

Try to tie strings between class topics and <u>your</u> favorite subjects

S p r e a d out learning

Repeat (practice) the material
(It may seem silly reading the same stuff over again, but that's what brains need to learn!)

Be effective with your time (always do what works best for you)

What is a Science?

Idea generation with the support of evidence.

Three ways of doing this:
Deductive, Inductive, Abductive

What is Engineering?
Problem solving with the support of evidence.

Deductive reasoning:

The scientific method uses deduction to test a hypothesis.

Pennies have a copper exterior.

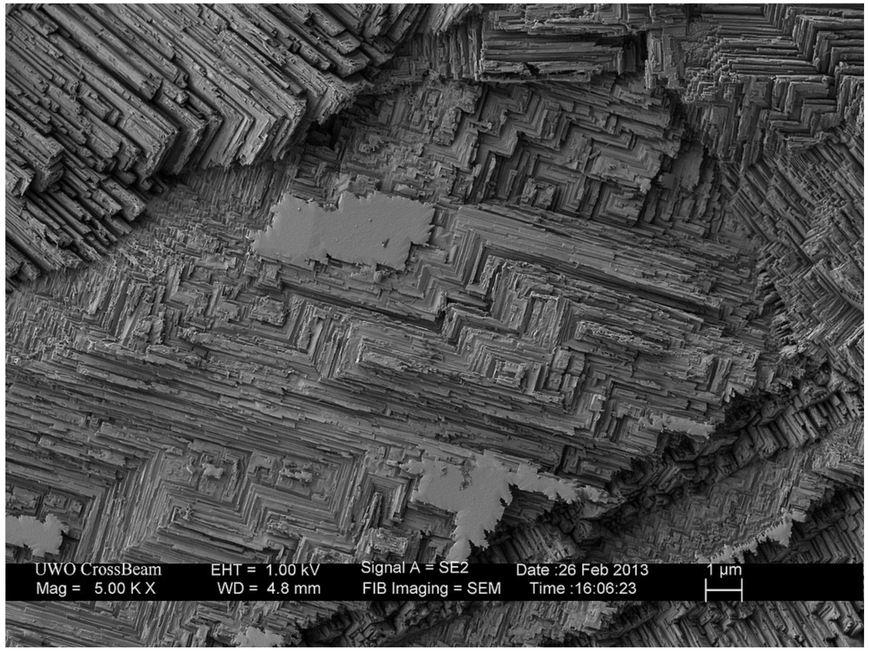
This coin is a penny.

This coin is coated in copper!

Question
Hypothesis
Experiment
Analysis
Conclusions
Share

Inductive reasoning:

I tested a jar with 89 pennies.
All of them had a copper shell with a zinc center.
All pennies must have a copper shells and zinc centers.



Abductive reasoning:

An incomplete set of observations is used to determine the most likely cases:

Yesterday I left 89 pennies in the jar in the bedroom.
Mr. Meowington was visting and spent the night in the bedroom.
Today the jar was knocked over, and there are no more pennies.

Mr. Meowington has decreased his net worthlessness by $ 0.89.

7	Buisness
3	Computer Science
3	Environmental Science
3	Film
3	Undecided
2	History
1	Anthropology
1	Communications
1	Engineering
1	English
1	Graphic Design
1	Journalism
1	Political Science
1	Psychology
1	Recreation and Leisure
1	Geology

Business cat does not recommend

Purrcrastination

The place businesses go to for solutions to their hardest problems they can't solve?

Managent Consultants

McKinsey&Company

BCG
THE BOSTON CONSULTING GROUP

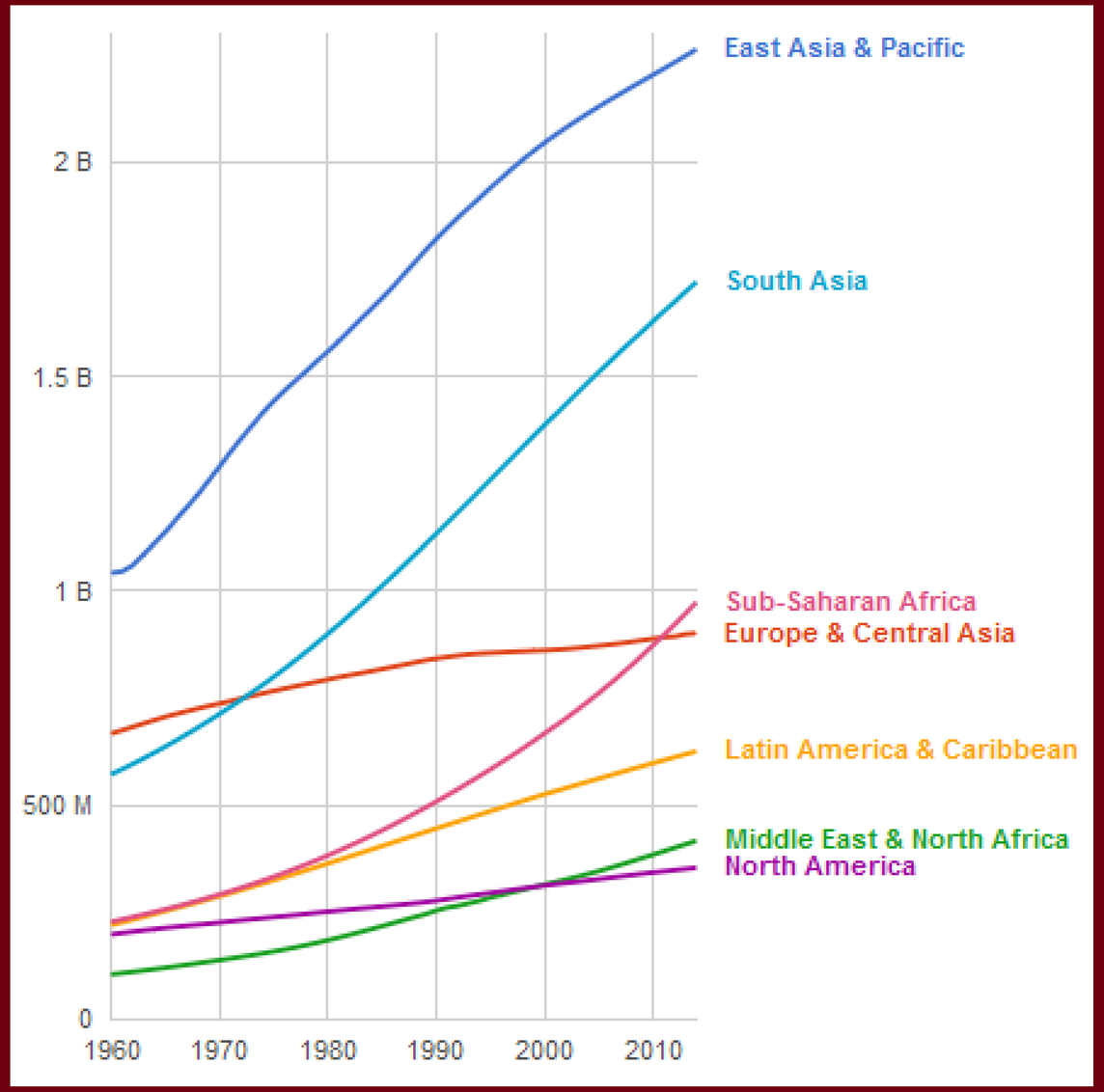
BAIN & COMPANY

About half business people who can speak the buisness language,
and half scientists/engineers who are just really good with data and drawing conclusions.

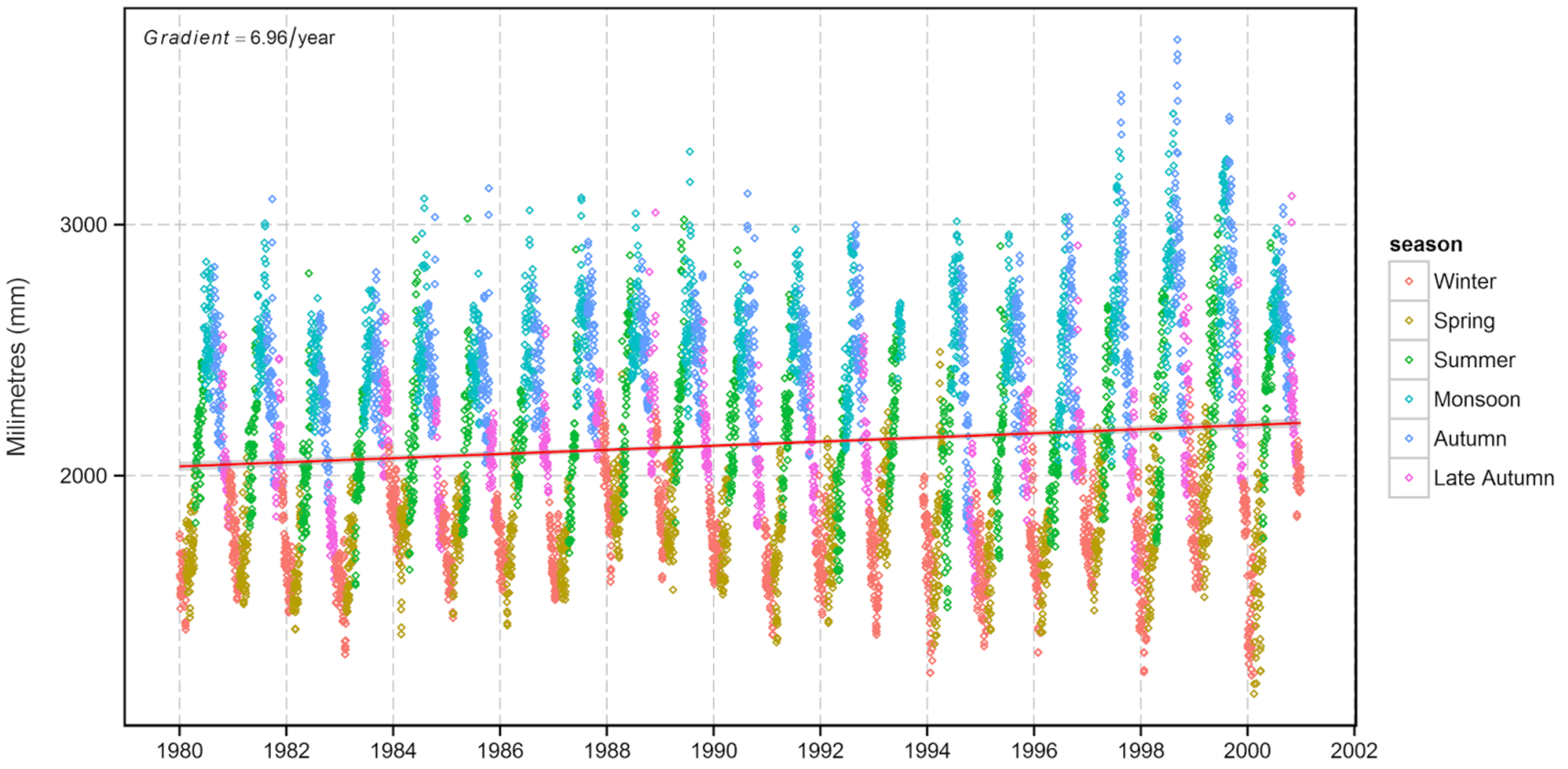
How to make a graph/how to read a graph

How to make a graph/how to read a graph

Are things the same or different?
How different are they?
Can we make a guess about data we dont have?

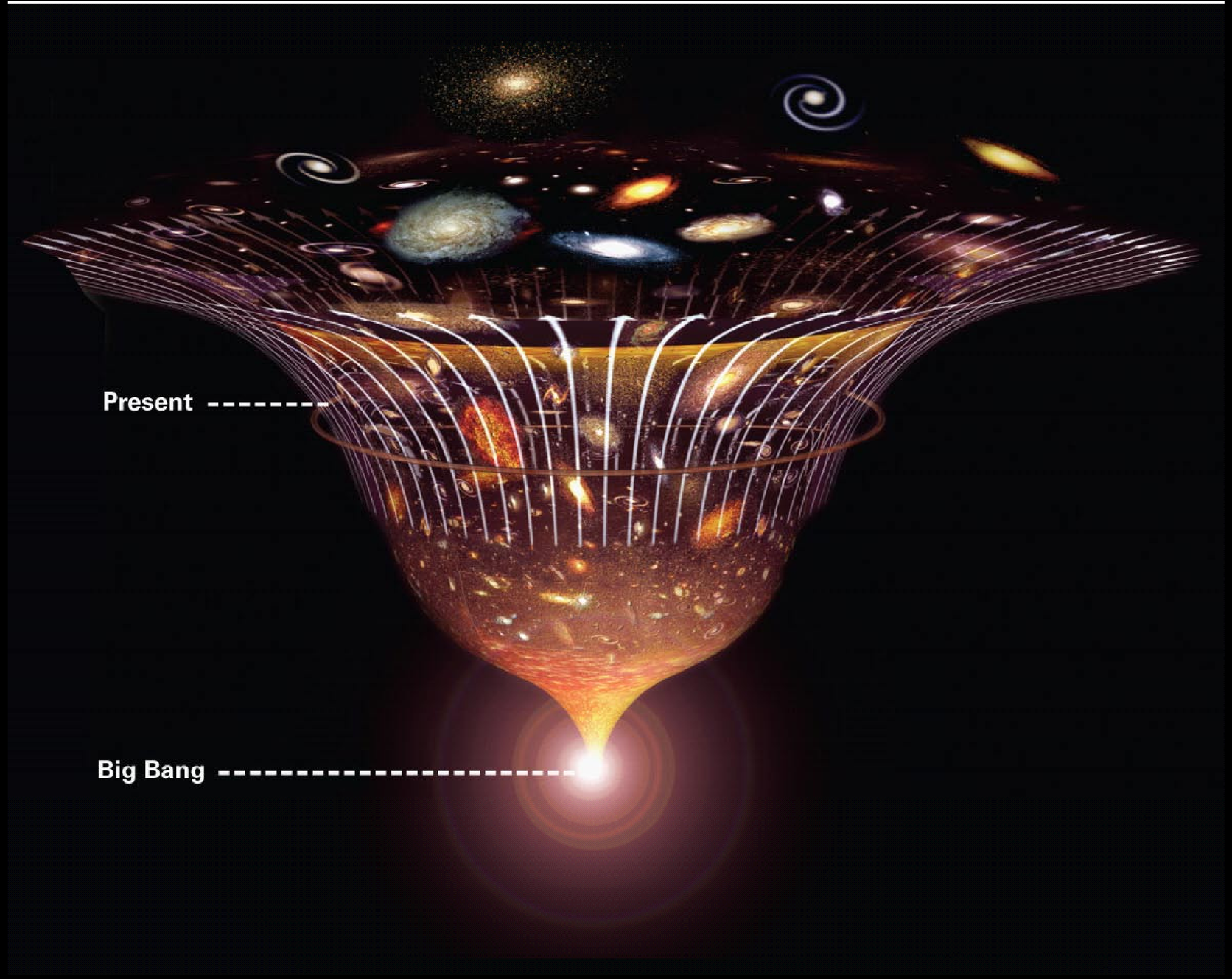

East Asia & Pacific
South Asia
Sub-Saharan Africa
Europe & Central Asia
Latin America & Caribbean
Middle East & North Africa
North America
2 B
1.5 B
1 B
500 M
0
1960
1970
1980
1990
2000
2010

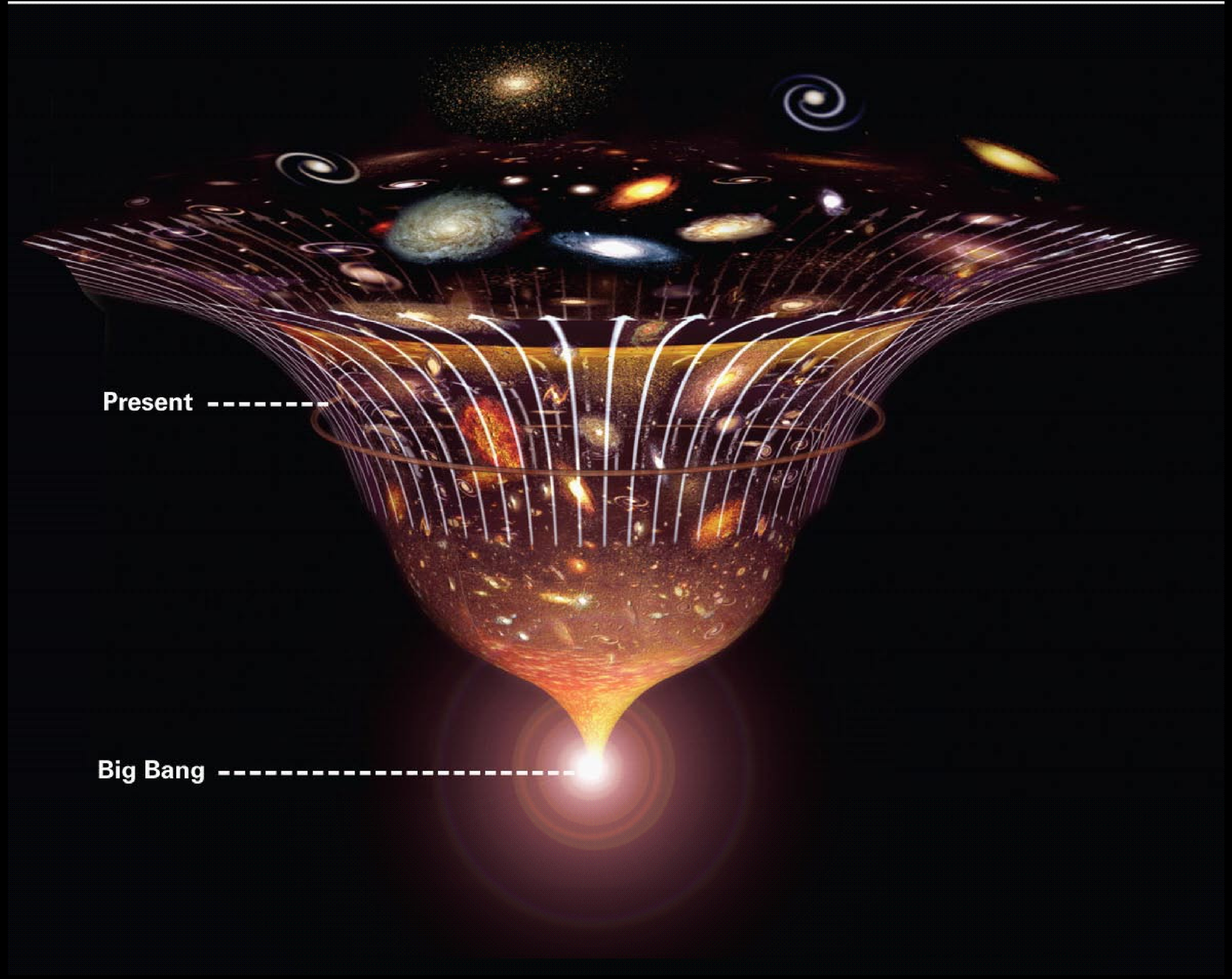
Sea Level at Charchanga - Bangladesh (1980-2000)



Source: University of Hawaii Sea Level Centre / Bangladesh Inland Water Transport Authority (BIWTA) - 2014

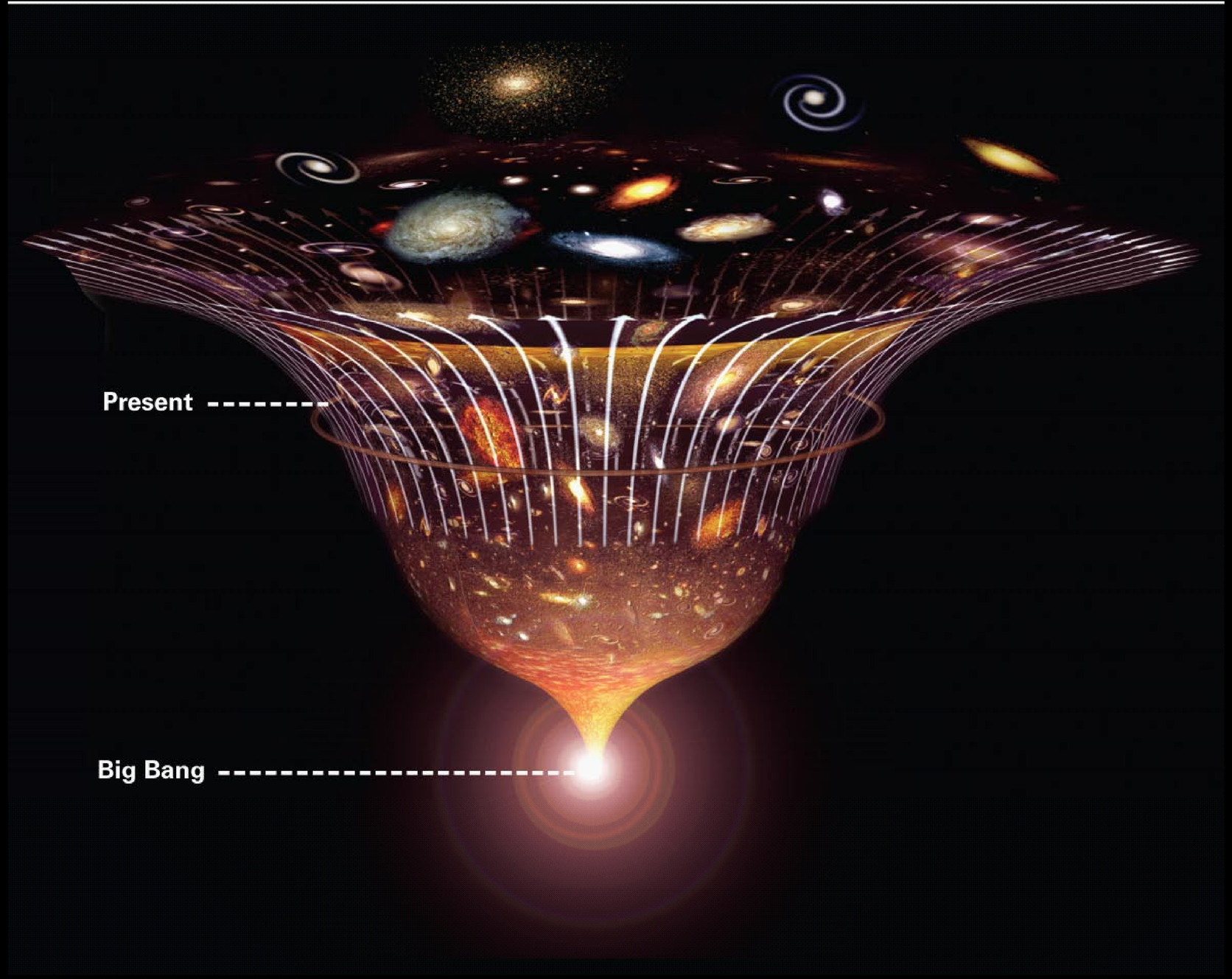
Making a Universe


Present
Big Bang



After the first 20 minunets of the big bang

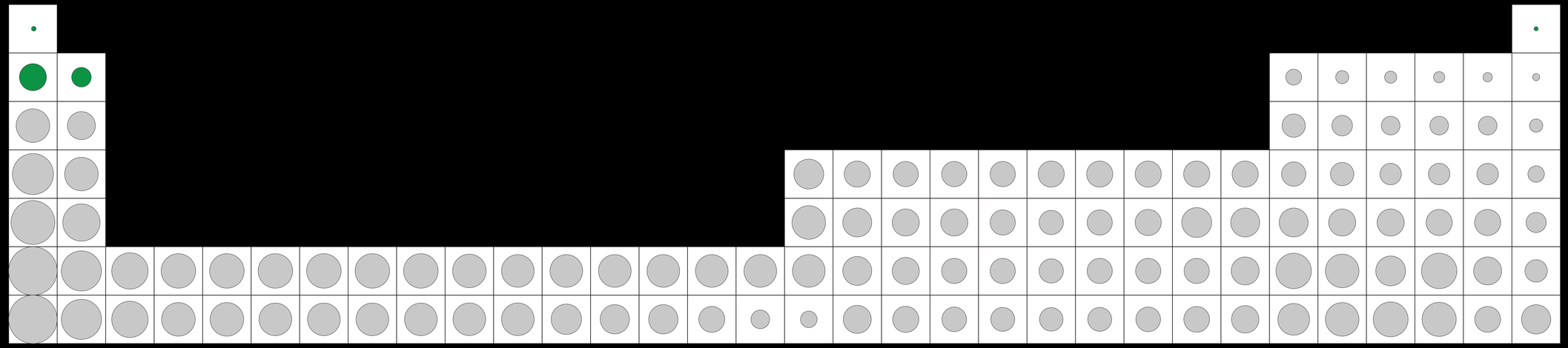
H, He, Li, Be



100 or so million years later, First (and giant) stars form

After the first 20 minunets of the big bang

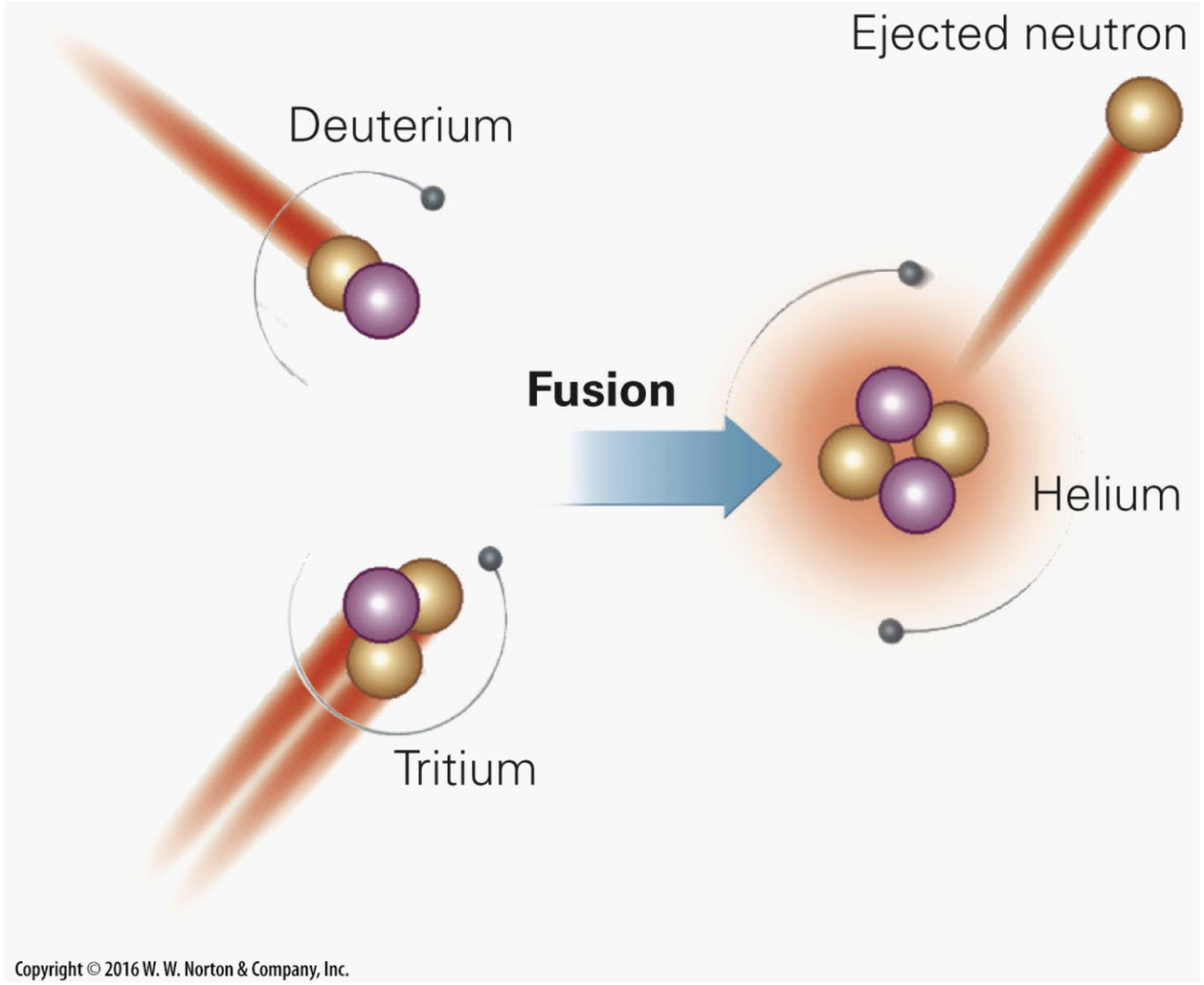
H, He, Li, Be

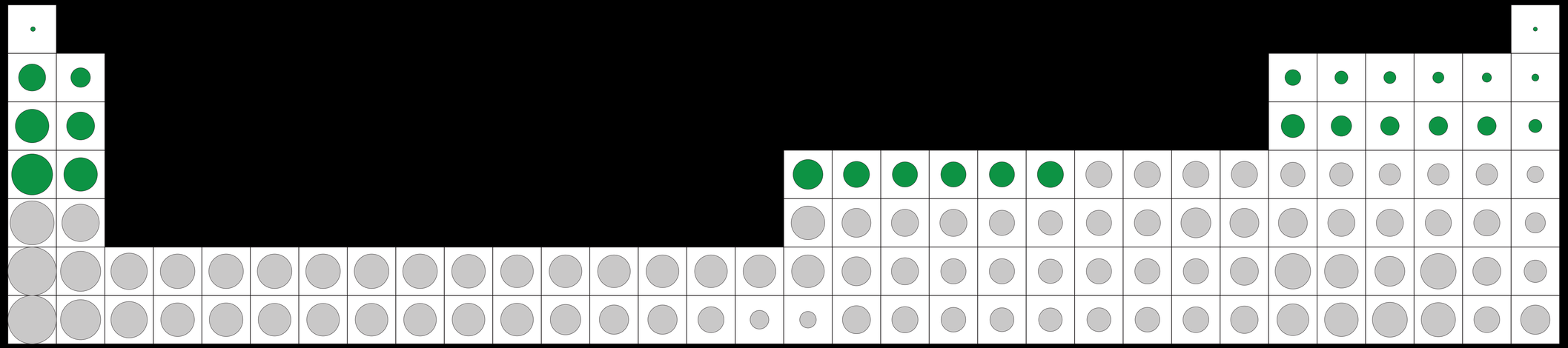


Fusion happens in stars

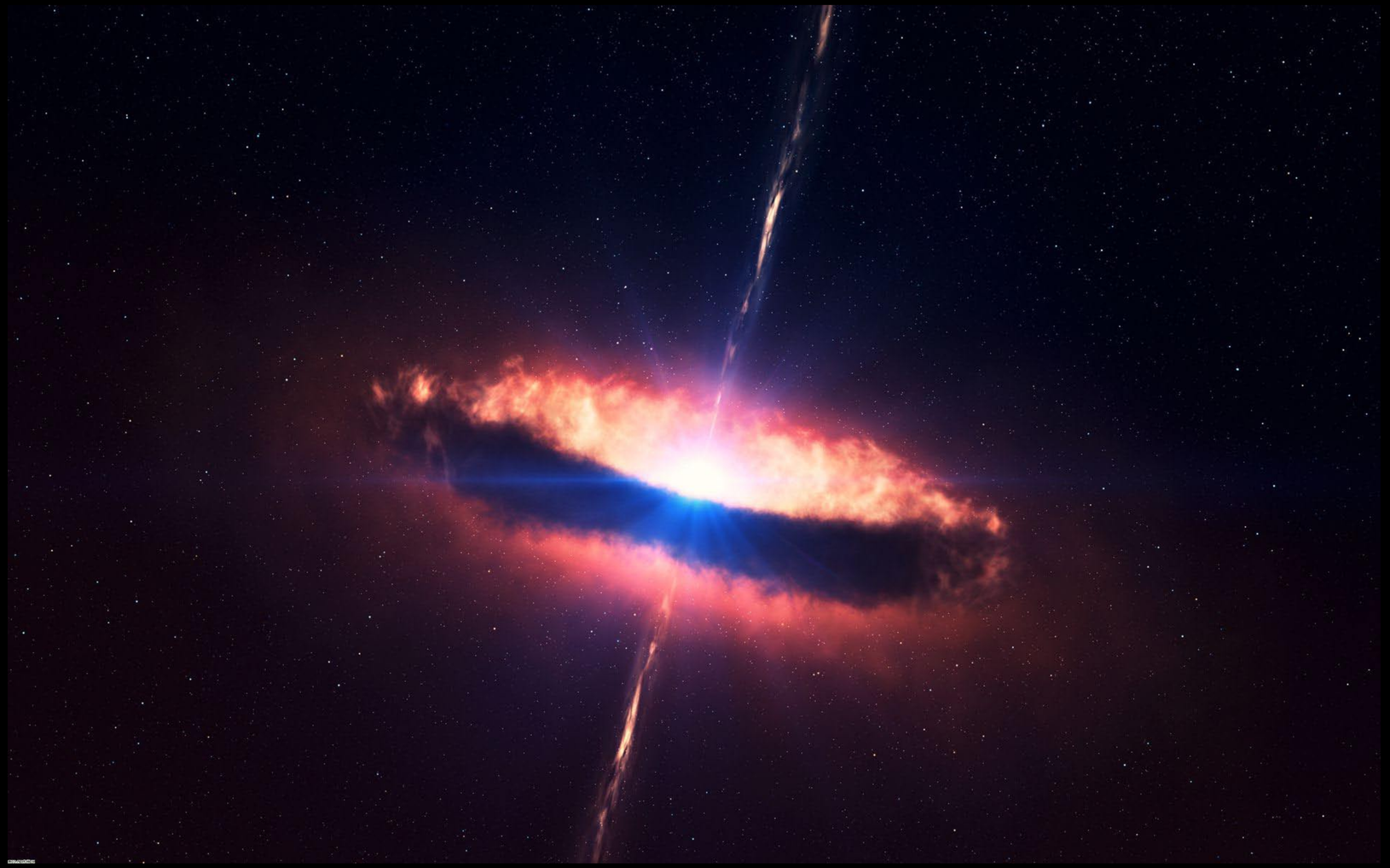
Type of H

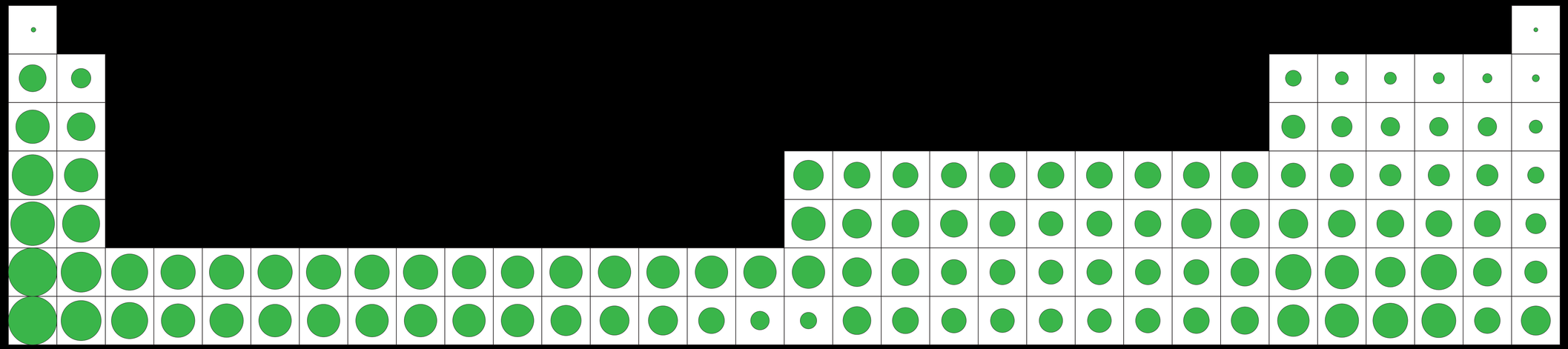
Type of H





Supernovas, Kilonovas





What is gravity?

Law of gravity says that masses are attracted to each other.
Just a description of what is observed.

Einstein's gravitational theory describes why masses are attracted to each other,
and predicted gravity waves.
The theory try's to describe why something happens.

Hypothesis is grounded in the experiment:
If gravity waves exist, they should effect space time,
and we should be able to observe this

https://www.nytimes.com/video/science/100000004200661/what-are-gravitational-waves-ligo-black-holes.html

Sharing results is critical to science:
Not everyone agrees with every result.

Ideally results are reproducible
Records are kept so that results can be reproduced

Modern science depends on
trust and distrust across scientists
sharing of information

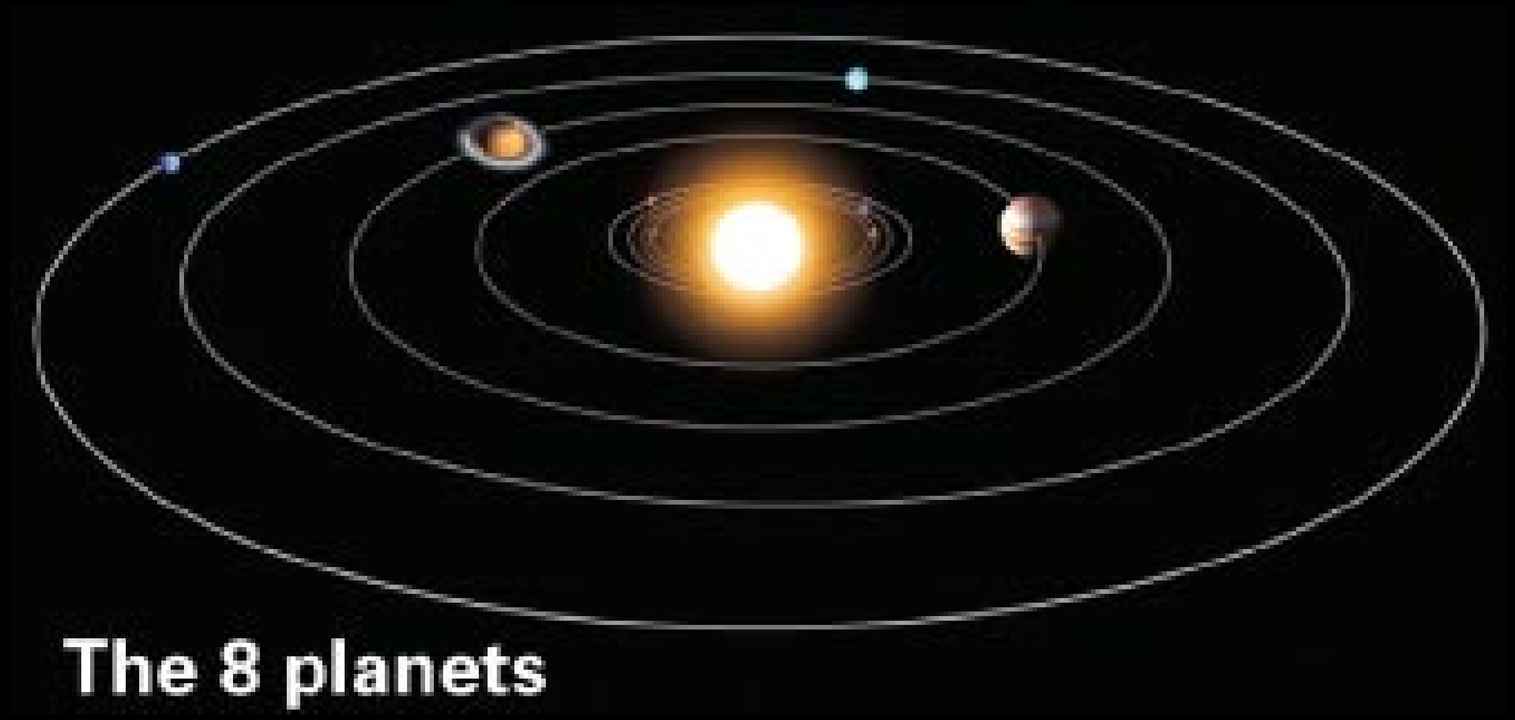
https://www.nytimes.com/video/science/100000005491113/detecting-a-kilonova-explosion.html

Forming the earth

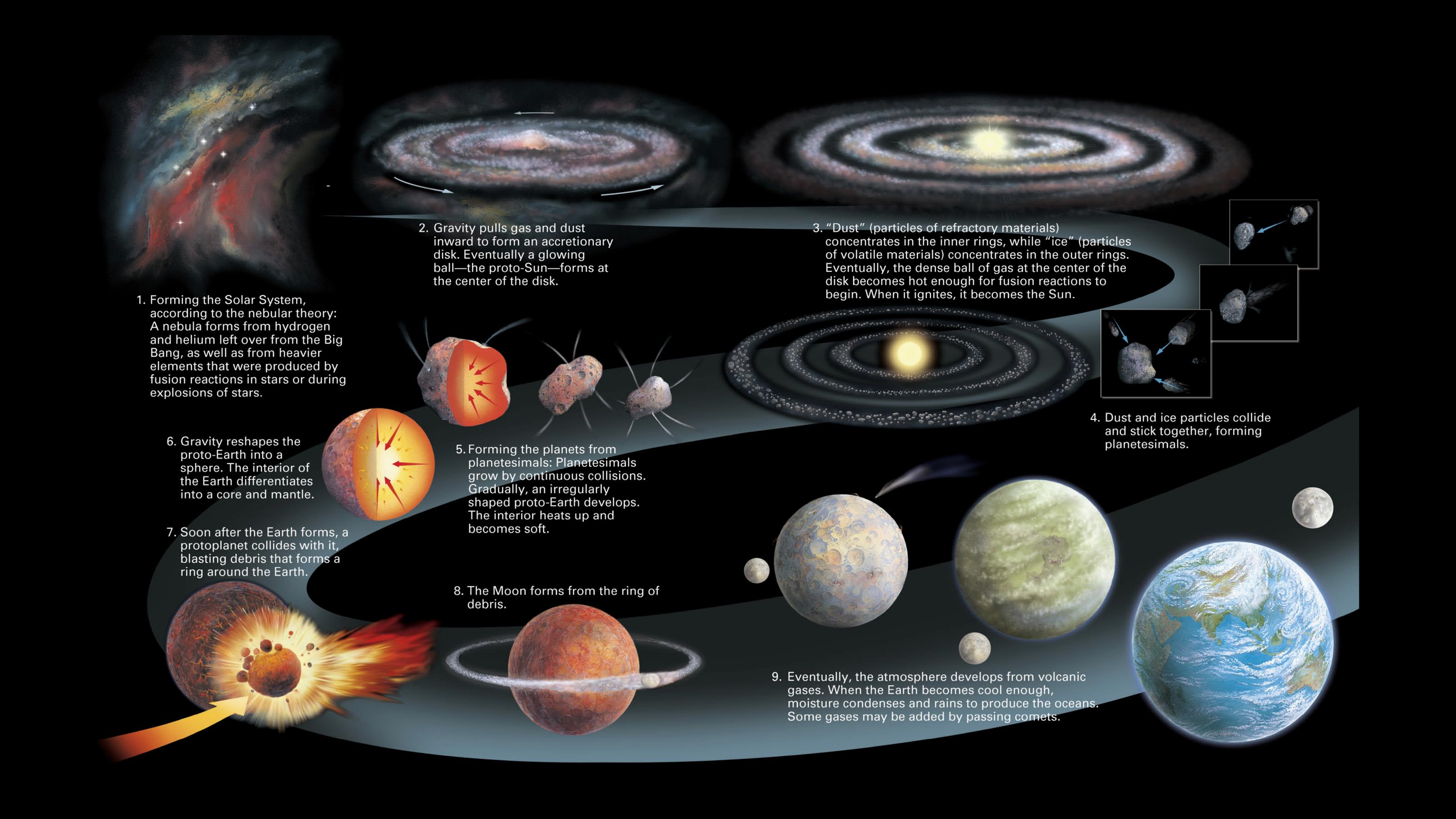

Nebula


Protoplanetary disk

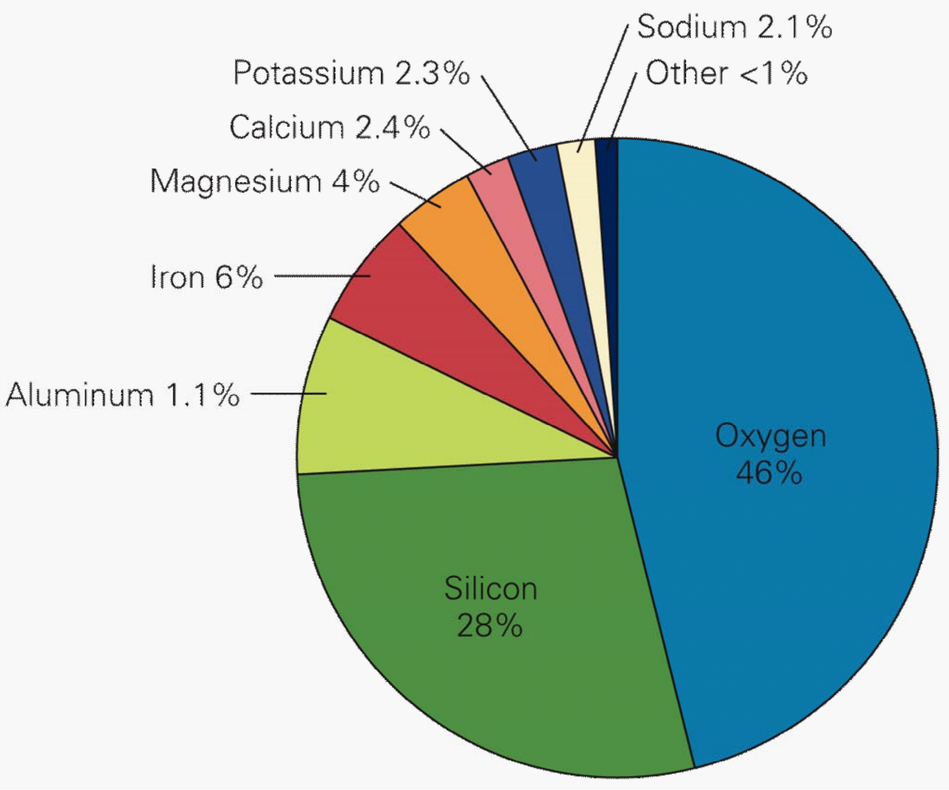
Rings of planetesimals



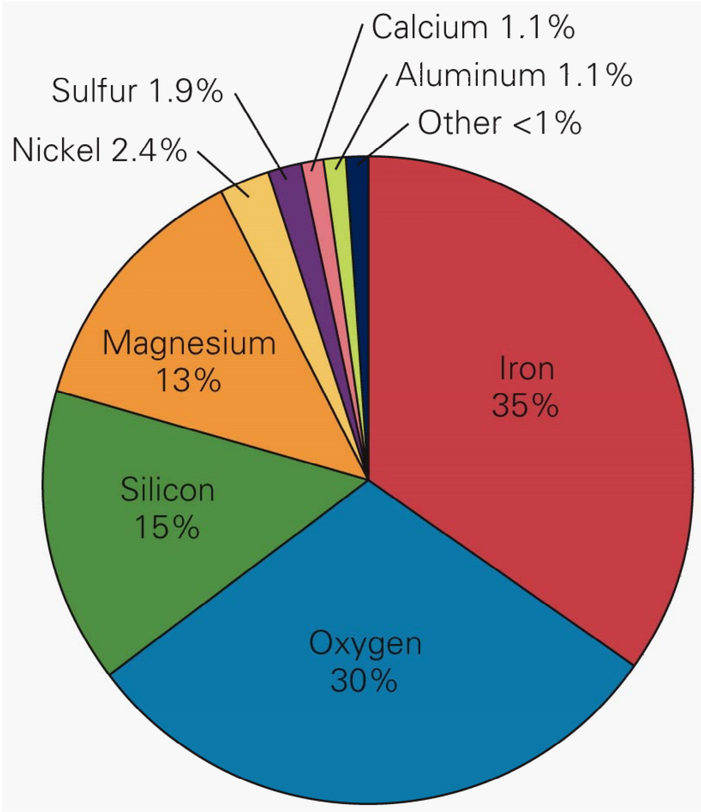
The 8 planets


1. Forming the Solar System, according to the nebular theory: A nebula forms from hydrogen and helium left over from the Big Bang, as well as from heavier elements that were produced by fusion reactions in stars or during explosions of stars.
2. Gravity pulls gas and dust inward to form an accretionary disk. Eventually a glowing ball—the proto-Sun—forms at the center of the disk.
3. "Dust" (particles of refractory materials) concentrates in the inner rings, while "ice" (particles of volatile materials) concentrates in the outer rings. Eventually, the dense ball of gas at the center of the disk becomes hot enough for fusion reactions to begin. When it ignites, it becomes the Sun.
4. Dust and ice particles collide and stick together, forming planetesimals.
5. Forming the planets from planetesimals: Planetesimals grow by continuous collisions. Gradually, an irregularly shaped proto-Earth develops. The interior heats up and becomes soft.
6. Gravity reshapes the proto-Earth into a sphere. The interior of the Earth differentiates into a core and mantle.
7. Soon after the Earth forms, a protoplanet collides with it, blasting debris that forms a ring around the Earth.
8. The Moon forms from the ring of debris.
9. Eventually, the atmosphere develops from volcanic gases. When the Earth becomes cool enough, moisture condenses and rains to produce the oceans. Some gases may be added by passing comets.

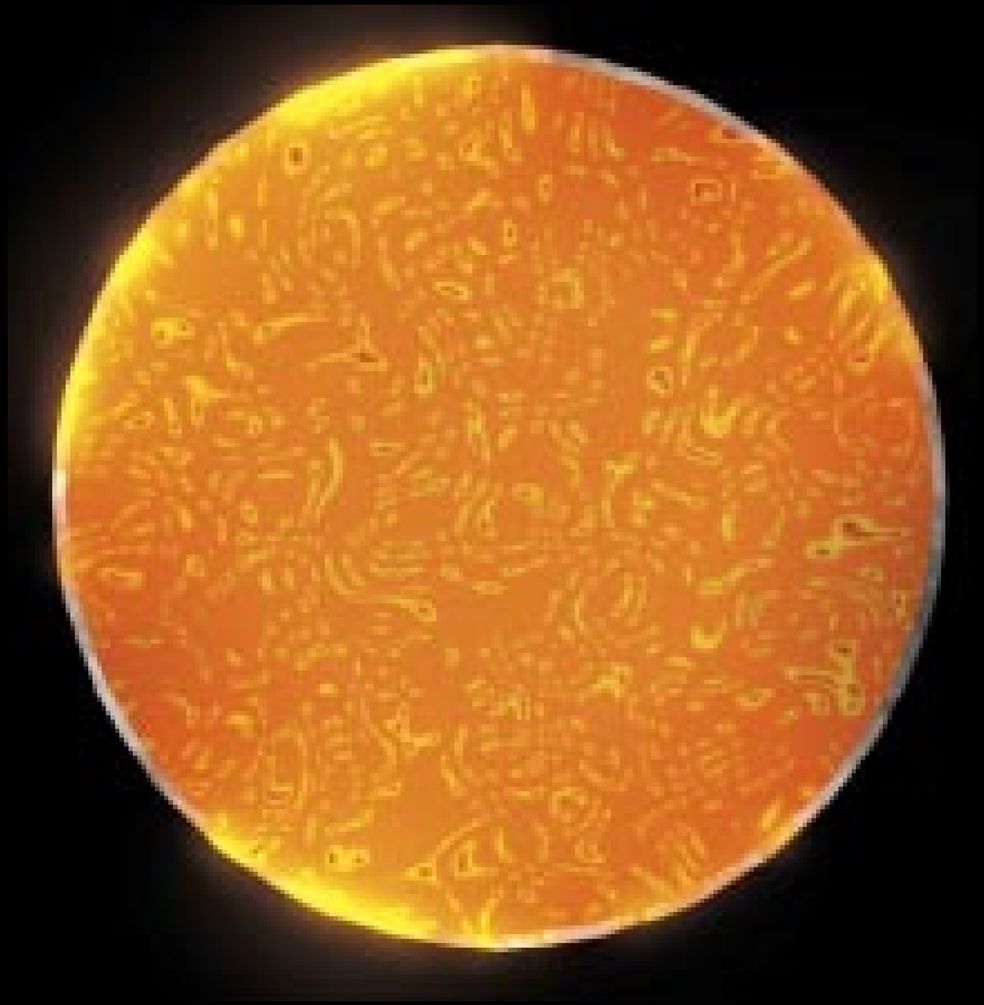
Why is the composition of the Earth so different on the crust?

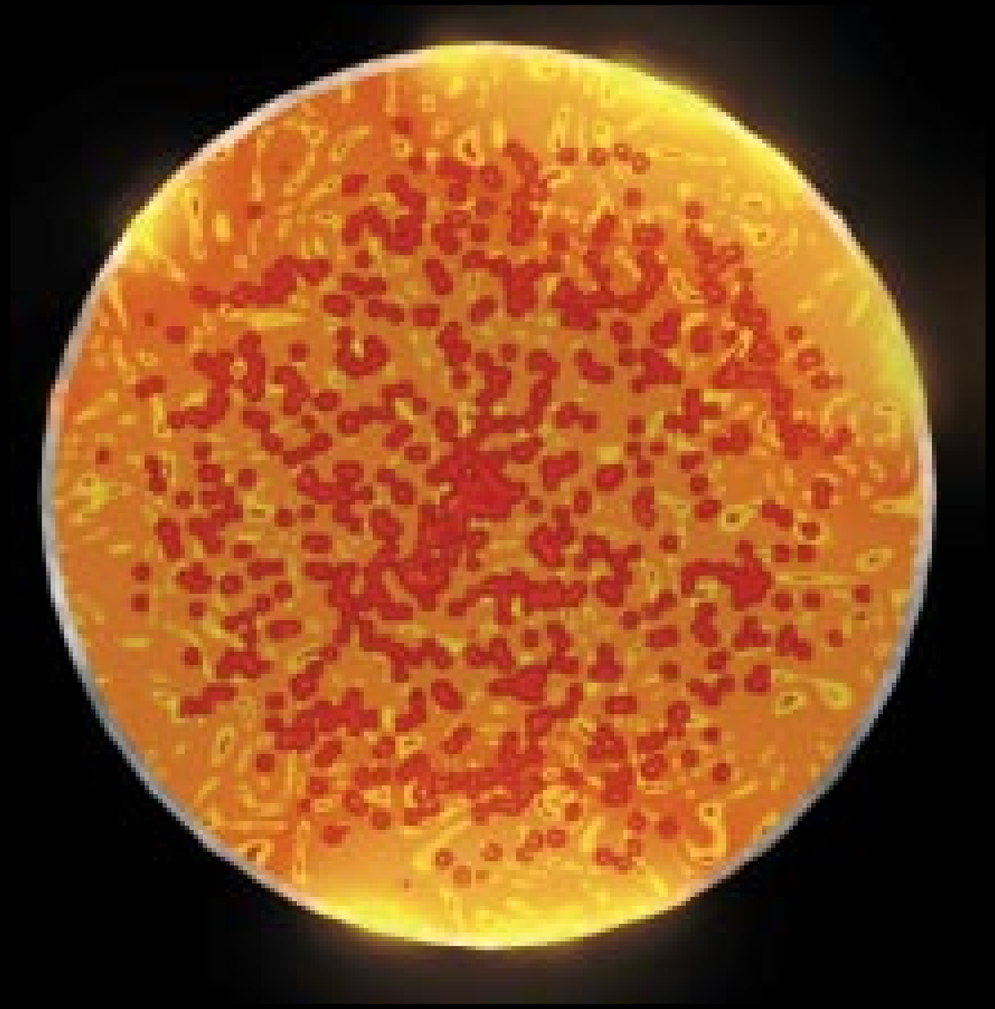


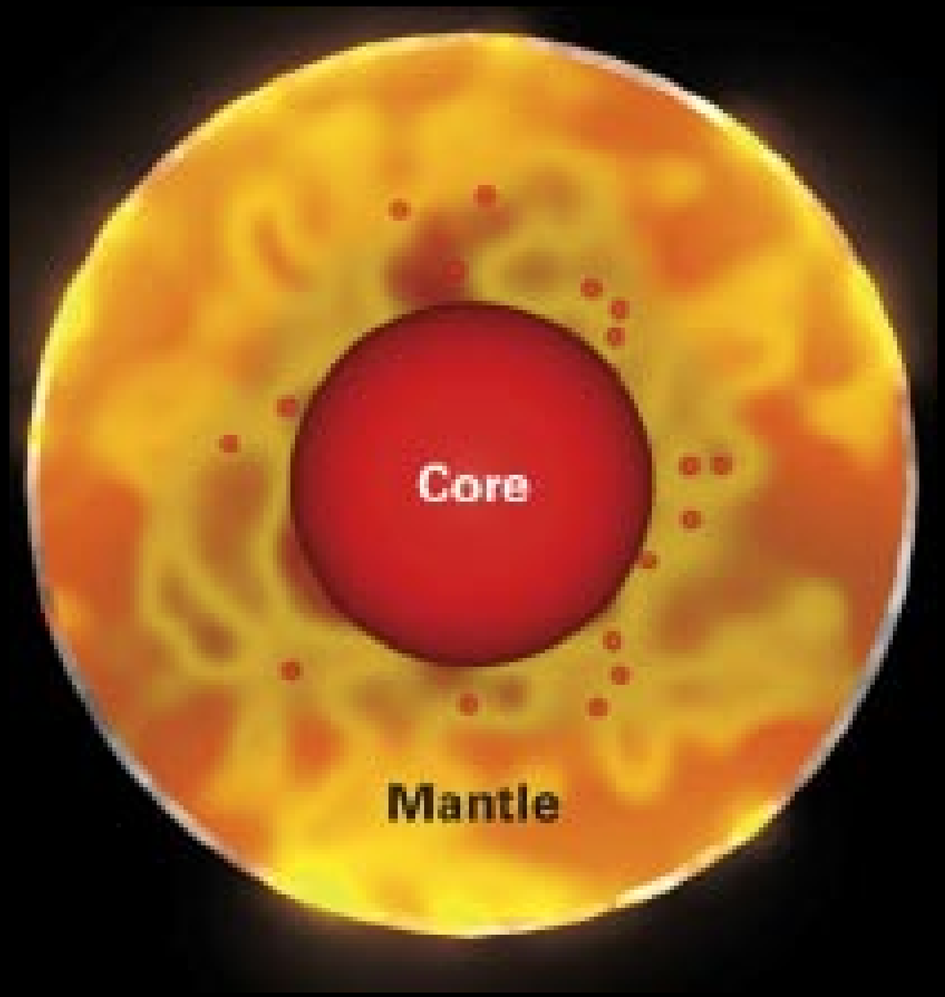
Crust Only

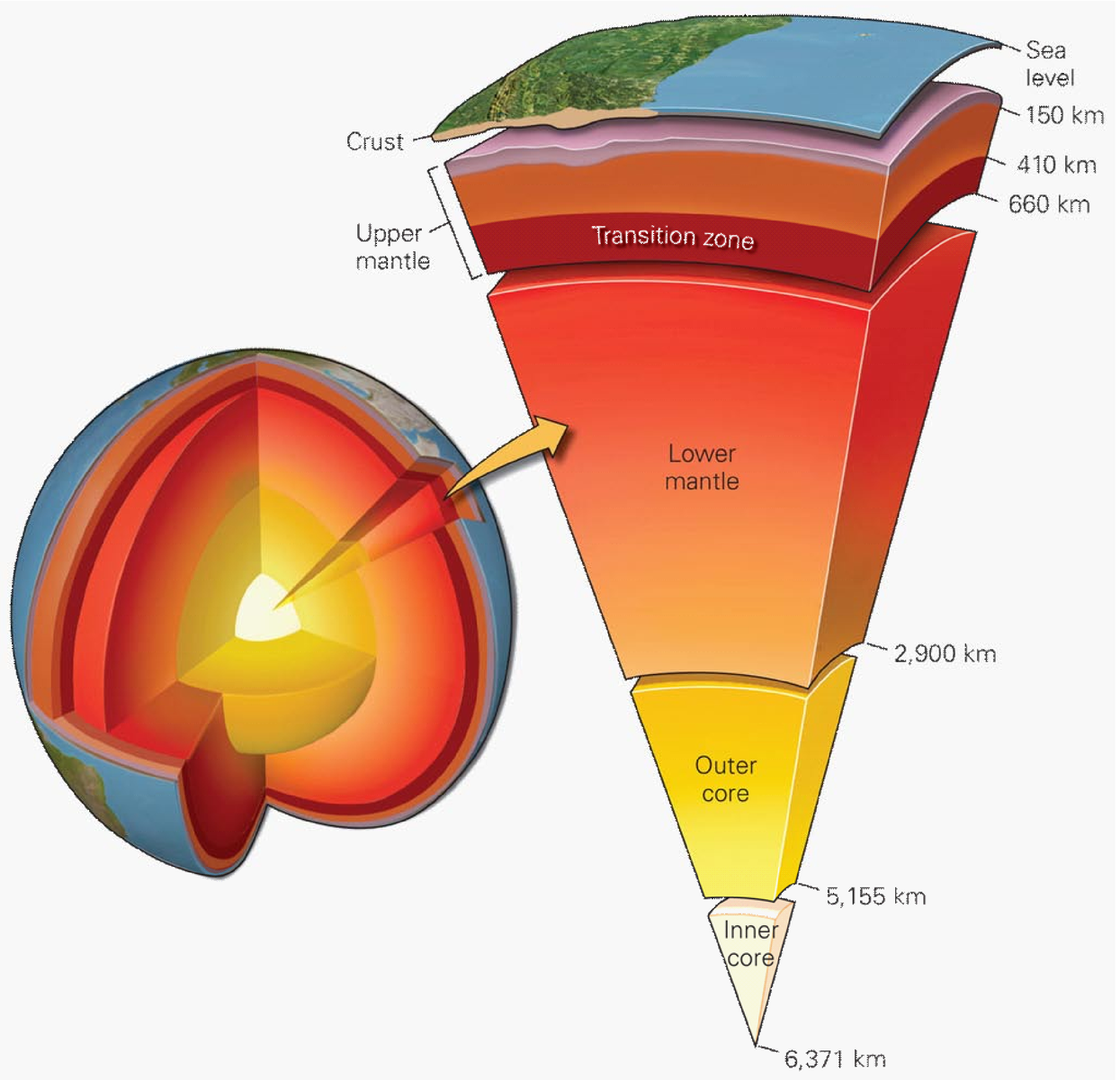


Entire Earth

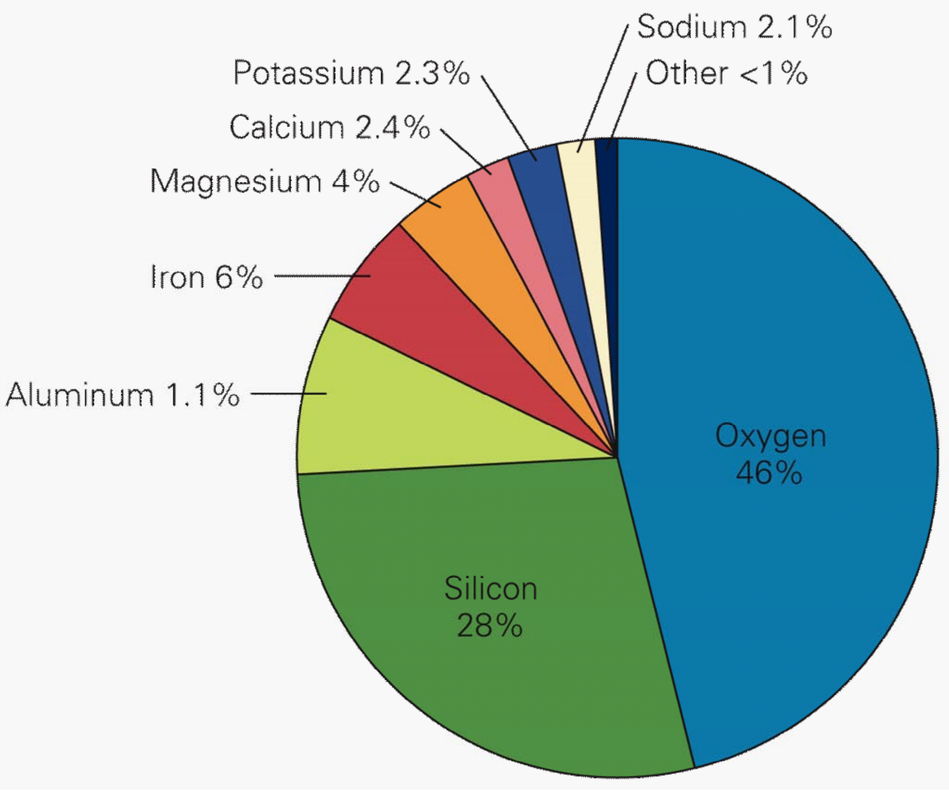




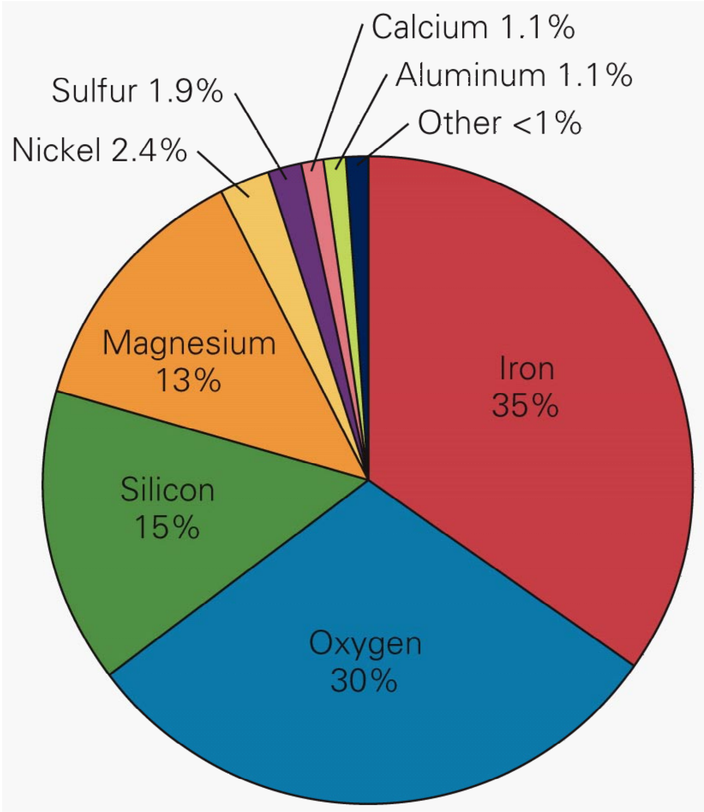

Core
Mantle


Sea level
150 km
410 km
660 km
Crust
Upper mantle
Transition zone
Lower mantle
2,900 km
Outer core
5,155 km
Inner core
6,371 km

Why didn't all the elements separate out?



Crust Only



Entire Earth

Phases of matter

Borax
(Actually Tincalconite)

$Na_2B_4O_7 \cdot 5H_2O$

Can save the day/play on stage

Phases of mater

Liquid

Phases of mater

Solid

Liquid

Vapor

Phases of mater

Solid

Liquid

Vapor

Phases of mater

Solid Melting ▶ Liquid Evaporation ▶ Vapor

Phases of mater

Solid

Melting ▶

◀ Freezing

Liquid

Evaporation ▶

◀ Condensation

Vapor

Borax
(Actually Tincalconite)

$Na_2B_4O_7 \cdot 5H_2O$

Melting around 200 C
(392 F)

Borax
(Actually Tincalconite)

$Na_2B_4O_7 \cdot 5H_2O$

Melting around 200 C
(392 F)

Borax
(Actually Tincalconite)

$Na_2B_4O_7 \cdot 5H_2O$

Melting around 200 C
(392 F)

Warm it up

Melting ▶

Evaporation ▶

Cooking up Geology
(Chemistry and Formulas)

Building Earth, a bit like cooking

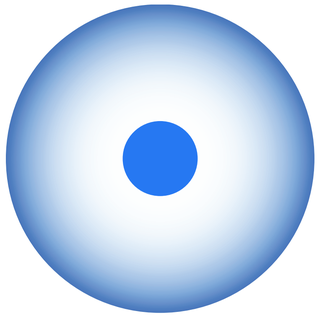
Basic ingredients

Each dish

Full meal

Building the earth, a bit like cooking

Basic ingredients



Atoms (elements)

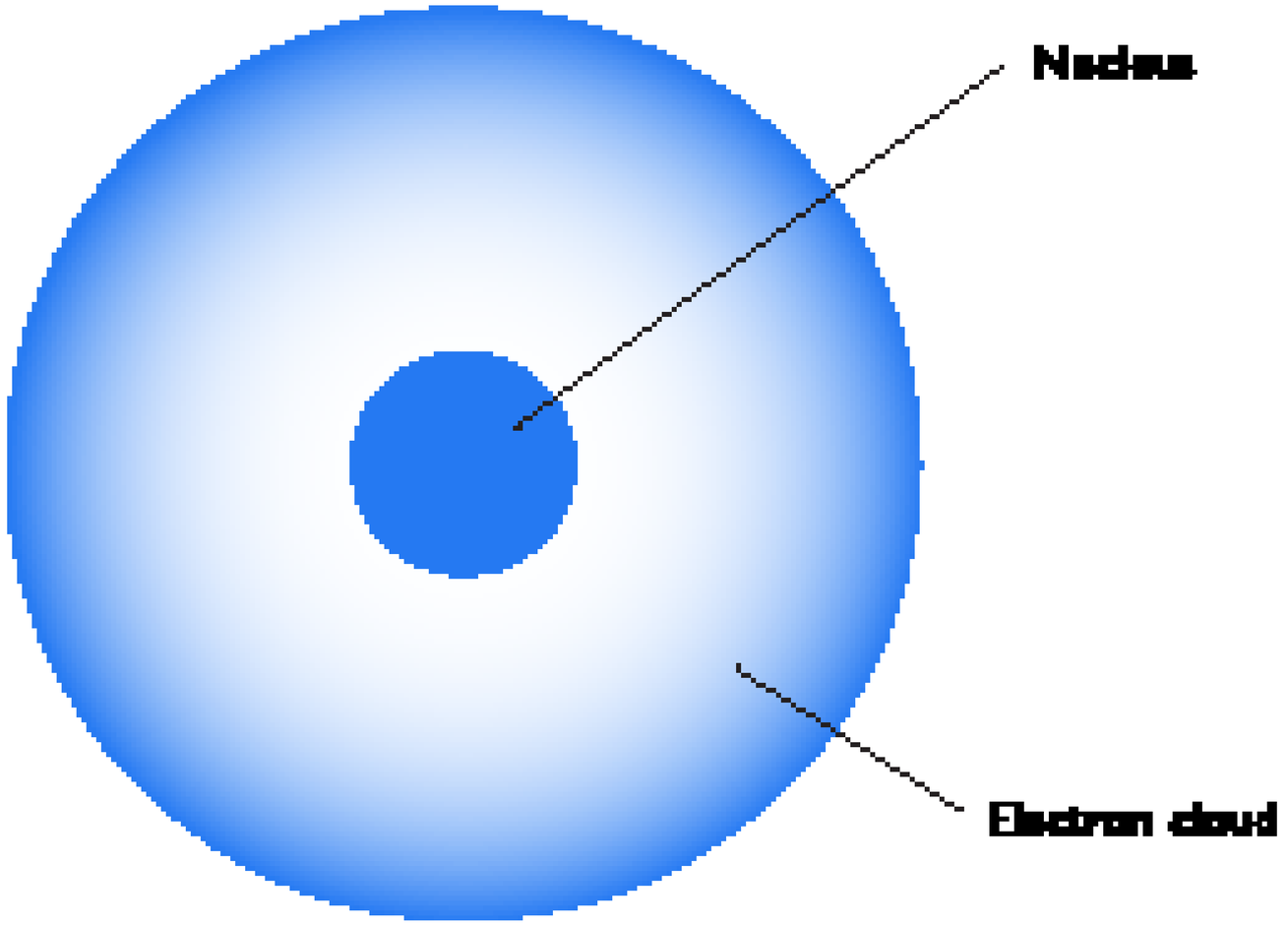
Each dish

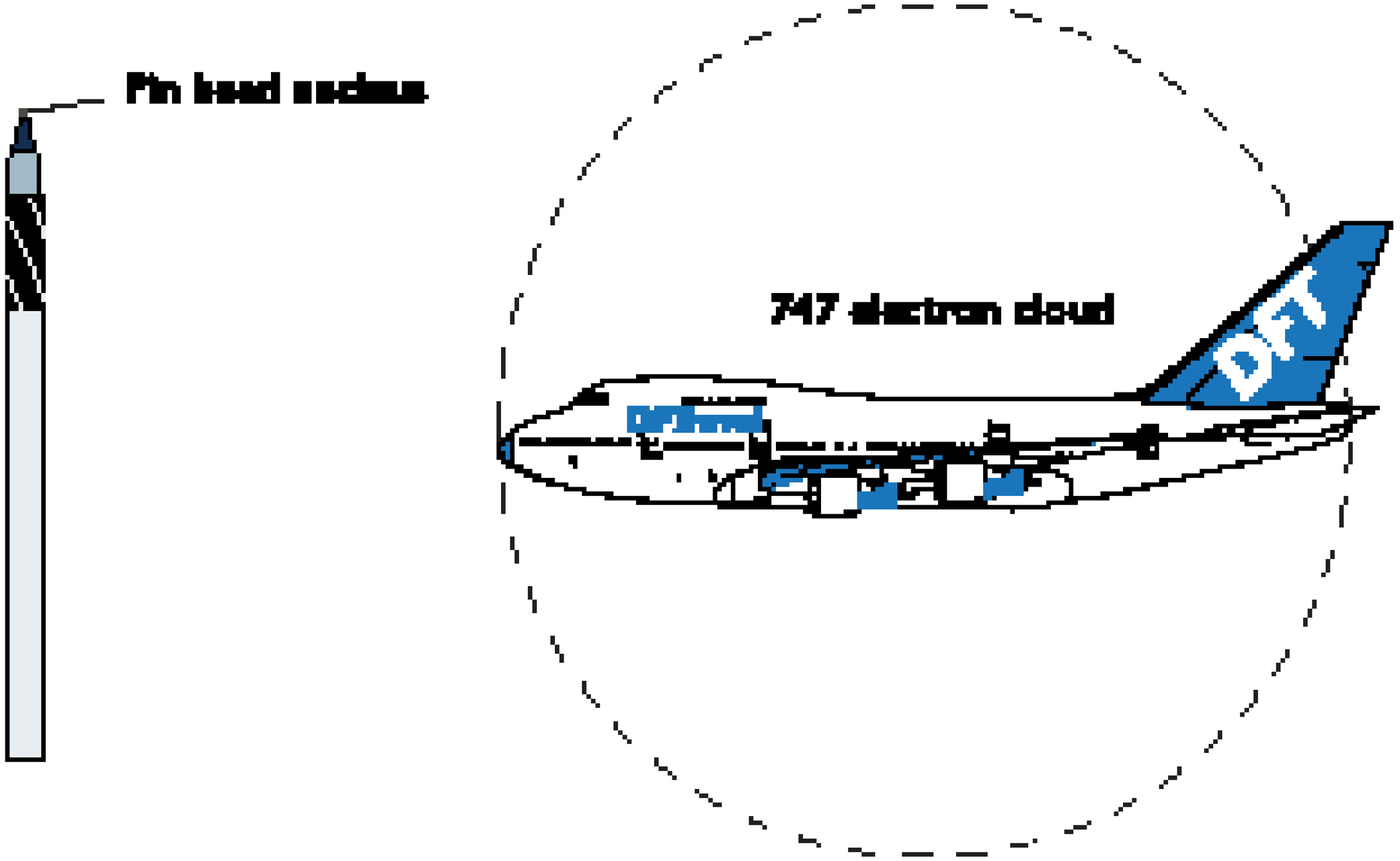
Minerals

Full meal

Rocks

Atoms don't look like this!

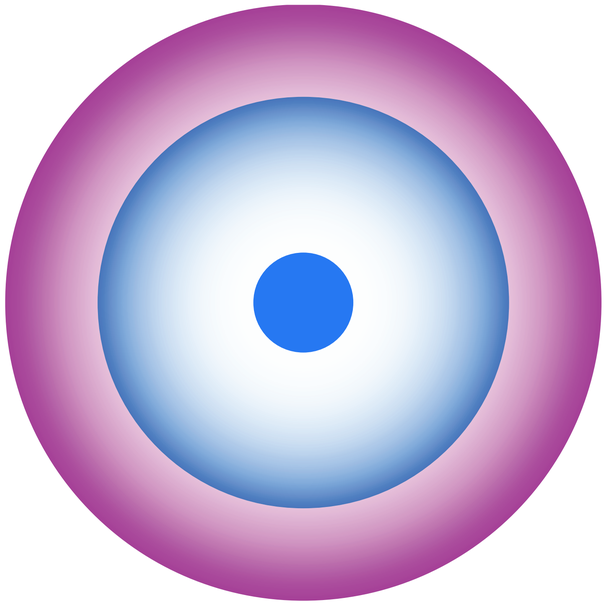


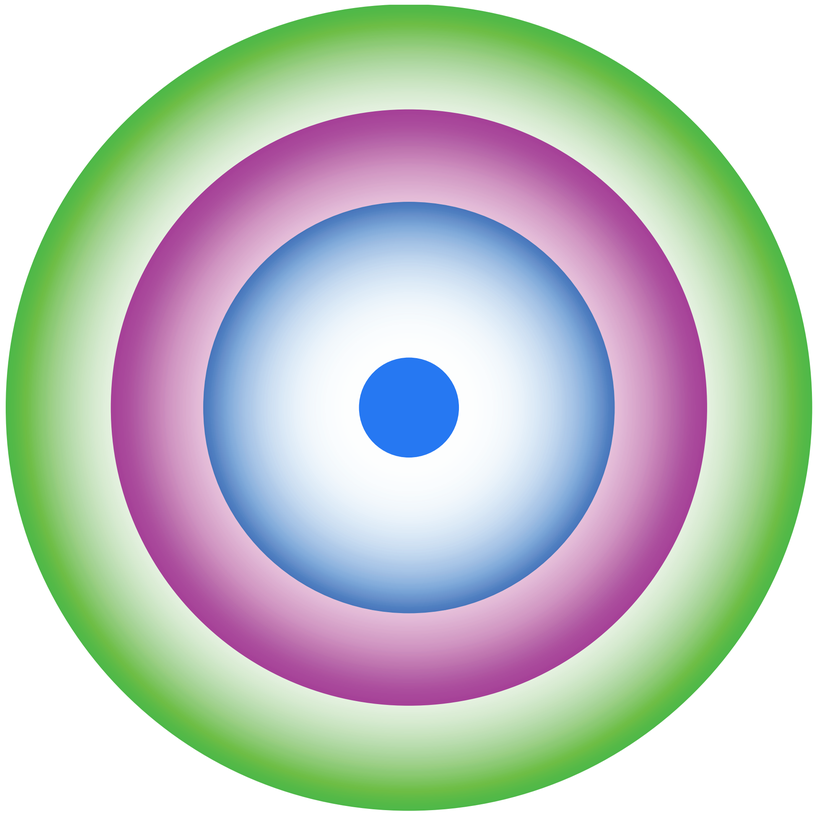

Pin lead nucleus
747 electron cloud

Earth electron cloud

747 nucleus

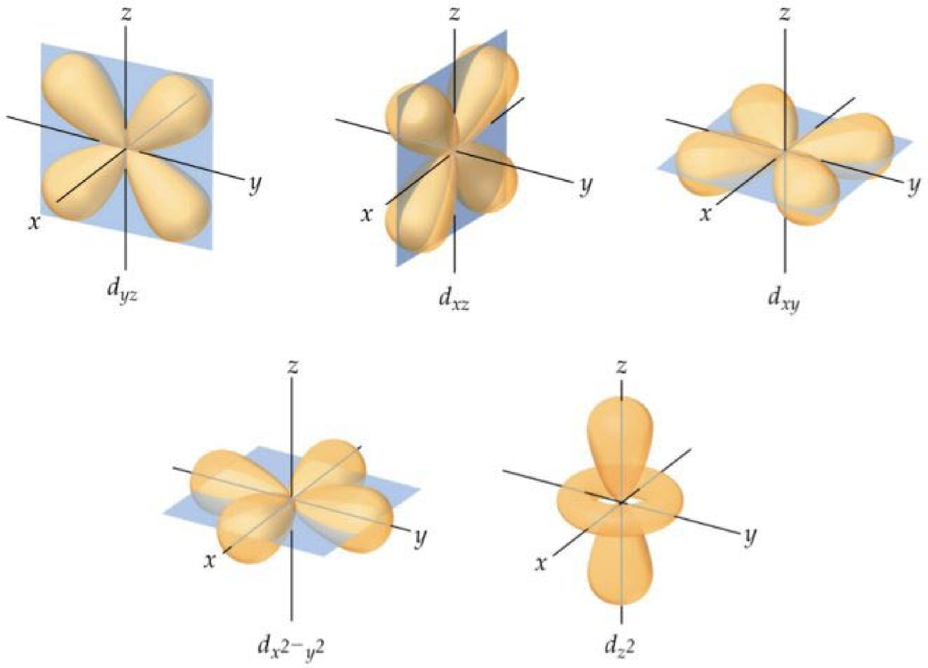
Nucleus of an atom has protons and neutrons (How heavy the atom is)
Shell of the atom has electrons (Most all of the atoms properties)



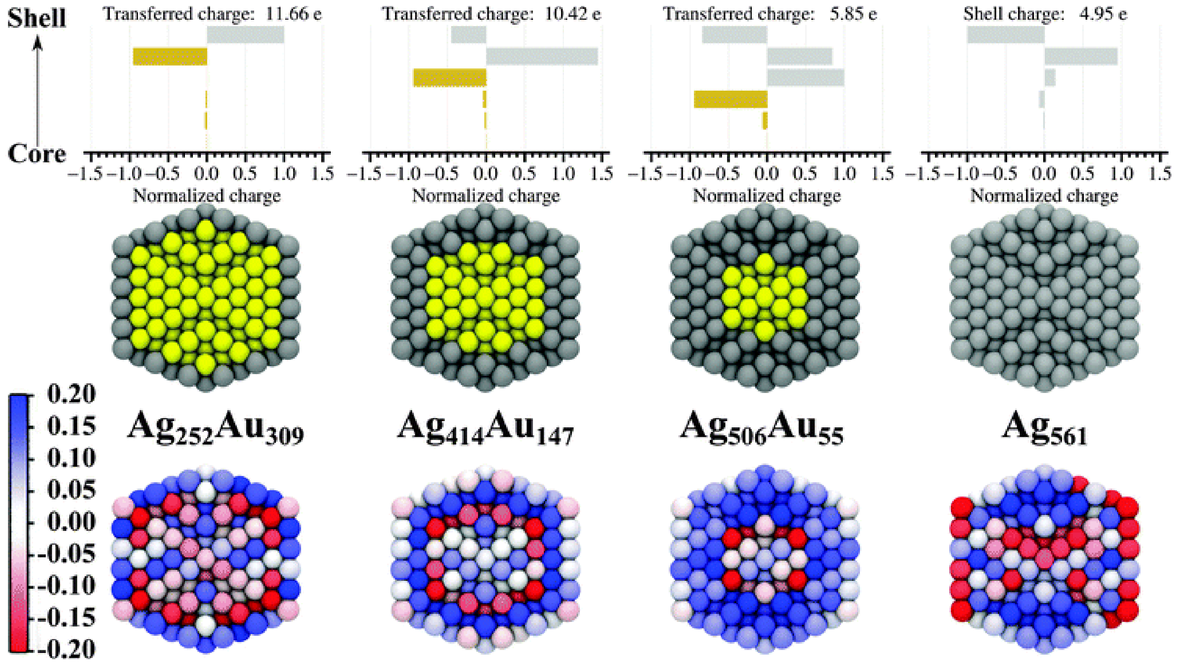


Electrons order themselves into shells

This is how physical chemists think about electron shells

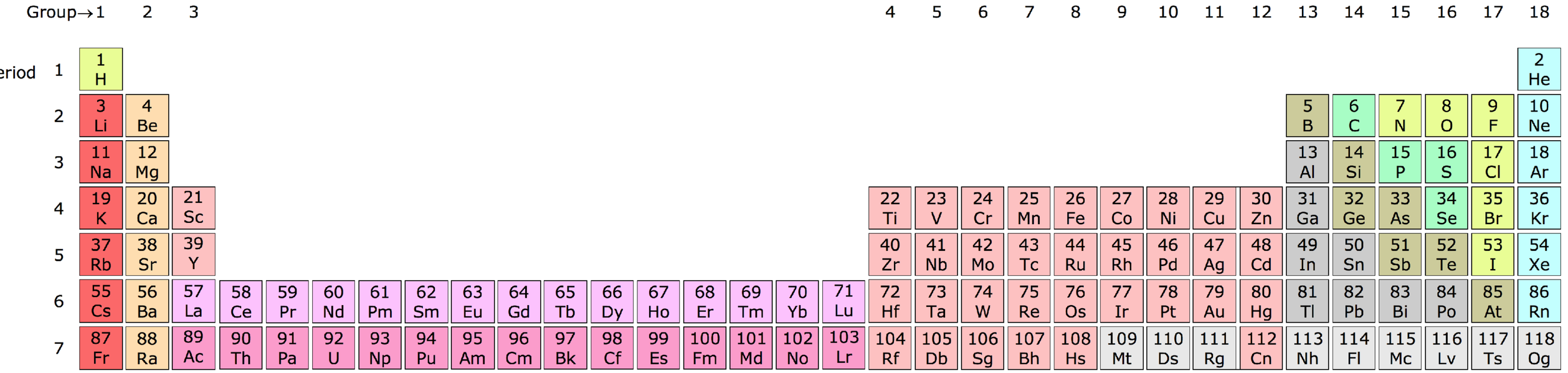


This is how materials chemists think about electron shells



Hard sphere model of an atom

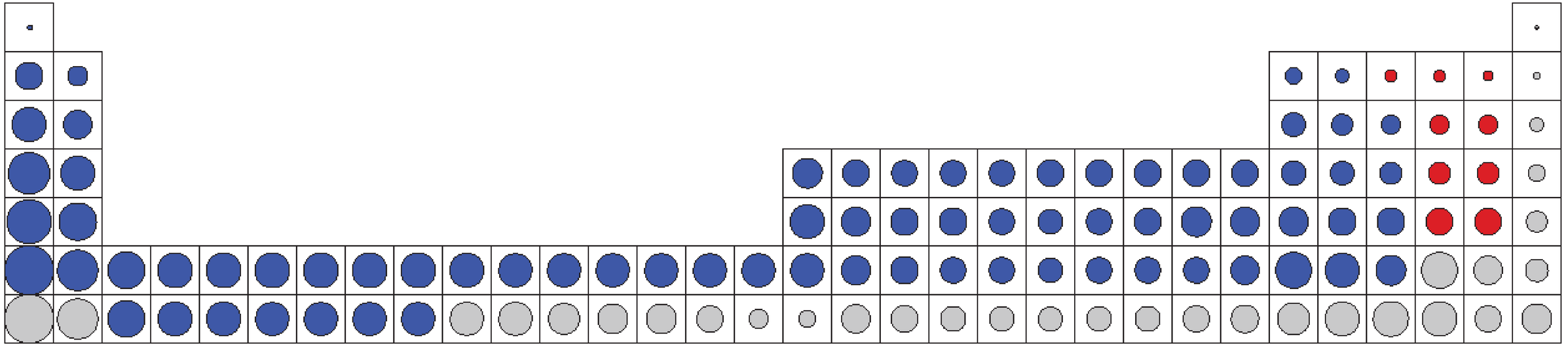
This is a big table! And in geology we see quite a bit of it. We need a good way to break it down



Charge

(geology always adds to zero)

Blue = Positive, Red = Negative



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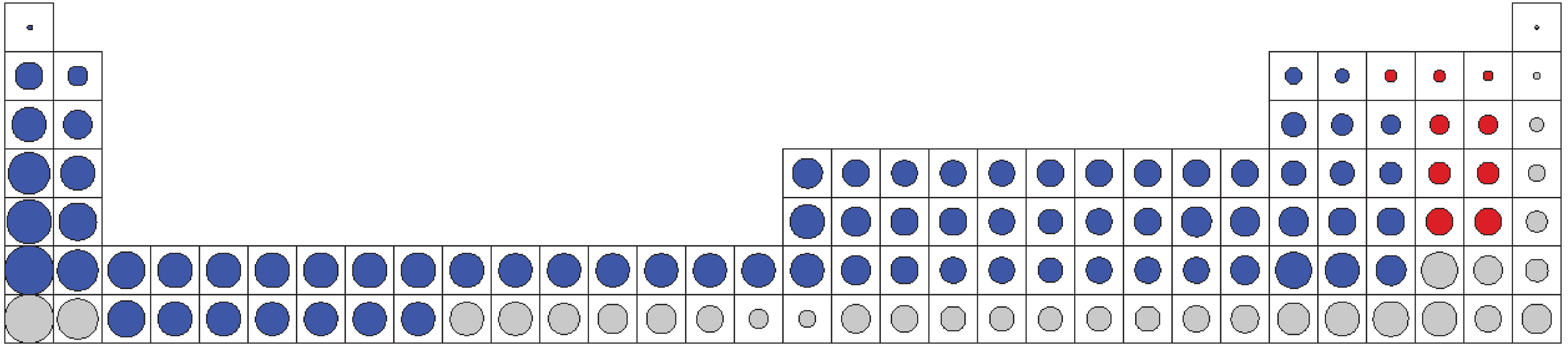
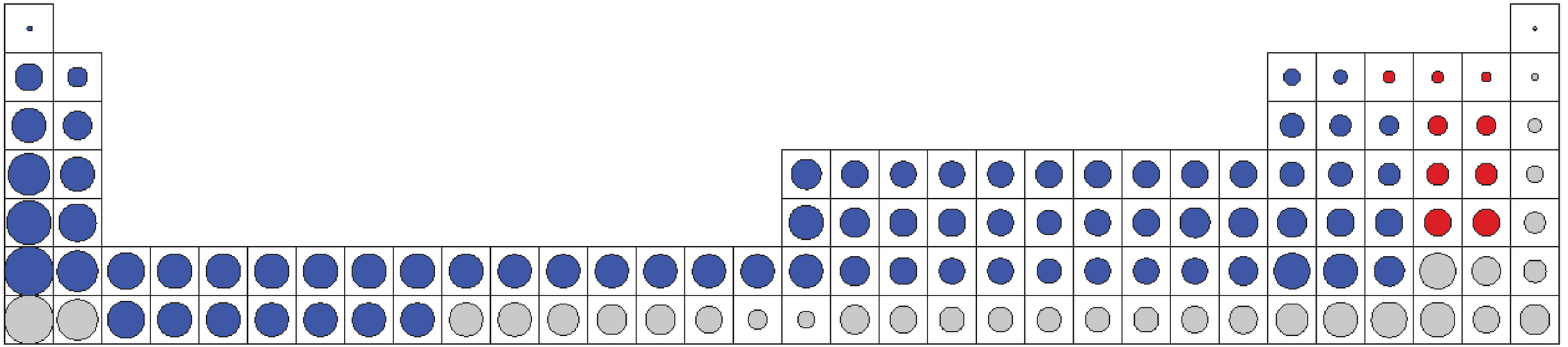
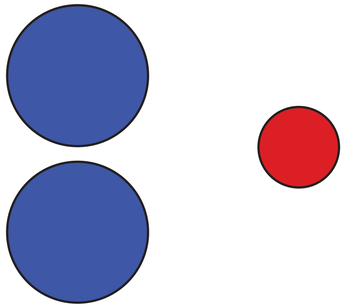
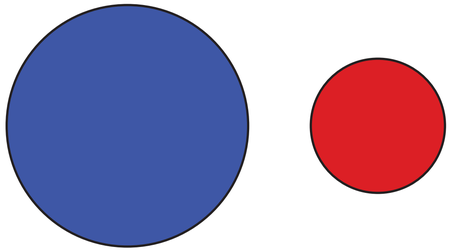


Size

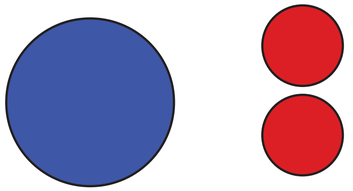




$Li_2 O$



Pb S



$Si O_2$

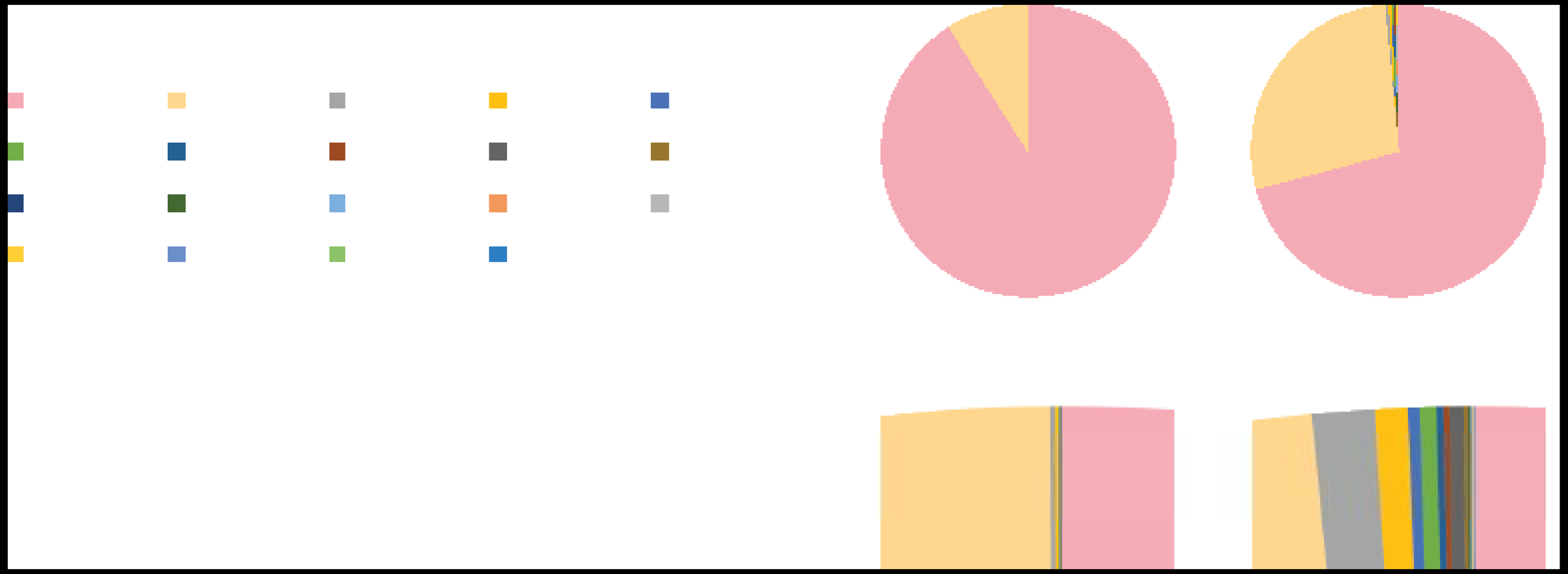
Thinking Diversity

In cooking:
How do we measure ingredients in the United States?
How do they measure ingredients in Europe?

How do scientists measure ingredents?

By atoms

By mass



Since most of geology deals with

Blue = Positive, Red = Negative

Talking geology in terms of atoms

Chemical formula (A bit like a recipe for cooking)

Boiled rice recipe

1 cup rice

2 cups water

Writing a chemical formula for boiled rice

$Rice_1 Water_2$

How much mineral?
(not too important)

Only the ratios are inportant

$Rice_1 Water_2$

$Rice_{0.5} Water_1$

$2(Rice_1 Water_2)$

Coconut rice recipe

1 cup rice

2 cups water

1/2 cup coconut

Writing a chemical formula for boiled rice

$Rice_1 Water_2 Coconut_{0.5}$

$Rice_4 Water_8 Coconut_2$

Sometimes it is very difficult to know the whole story

Rice = 2.003
Coconut = 0.992
Water = ?

$$\mathrm{Rice}_{2.003}\,\mathrm{Water}_{?}\,\mathrm{Coconut}_{0.992}$$

Sometimes it is very difficult to know the whole story

Rice = 2.003
Coconut = 0.992
Water = ?

We know the recipie!

Coconut rice recipe
1 cup rice
2 cups water
1/2 cup coconut

$$Rice_{2.003}\,Water_{?}\,Coconut_{0.992}$$

Sometimes it is very difficult to know the whole story

Rice = 2.003
Coconut = 0.992
Water = ?

We know the recipie!

Coconut rice recipe
1 cup rice
2 cups water
1/2 cup coconut

$$\text{Rice}_{2.003}\,\text{Water}_{?}\,\text{Coconut}_{0.992}$$

$$\text{Rice}_{(2.003 \div 2)}\,\text{Water}_{?}\,\text{Coconut}_{(0.992 \div 2)}$$

Sometimes it is very difficult to know the whole story

Rice = 2.003
Coconut = 0.992
Water = ?

We know the recipie!

Coconut rice recipe
1 cup rice
2 cups water
1/2 cup coconut

$$Rice_{2.003}Water_{?}Coconut_{0.992}$$

$$Rice_{(1.002)}Water_{?}Coconut_{(0.496)}$$

$$Rice_{1.002}Water_{2}Coconut_{0.496}$$

Sometimes it is very difficult to know the whole story

Rice = 2.003
Coconut = 0.992
Water = ?

We know the recipie!

Coconut rice recipe
1 cup rice
2 cups water
1/2 cup coconut

$Rice_{1.002}Water_{2}Coconut_{0.496}$

Olivine: $(Mg,Fe)_2Si_1O_4$

Olivine: $(Mg,Fe)_2Si_1O_4$

Comma means either one or both

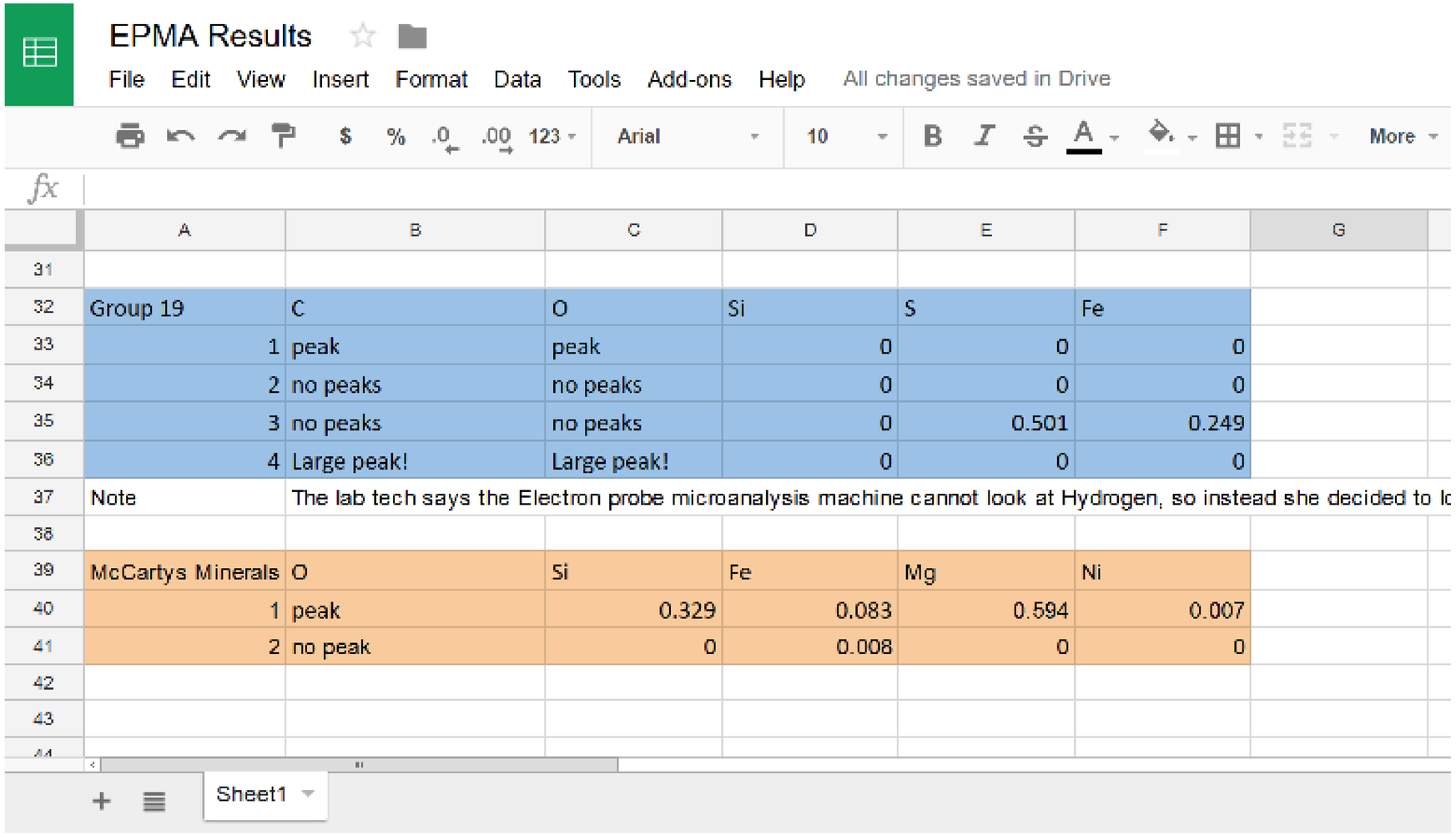
Mg^{2+} or Fe^{2+}

Canola oil, or Corn oil, or Avocado oil

$Canola^{oil}$ or $Corn^{oil}$ or $Avocado^{oil}$

$Canola^{oil}_{\text{(one cup worth)}}$ or $Corn^{oil}_{(1)}$ or $Avocado^{oil}_{(1)}$

Olivine: $(Mg,Fe)_2Si_1O_4$



EPMA Results

File Edit View Insert Format Data Tools Add-ons Help All changes saved in Drive

	A	B	C	D	E	F	G
31							
32	Group 19	C	O	Si	S	Fe	
33	1	peak	peak	0	0	0	
34	2	no peaks	no peaks	0	0	0	
35	3	no peaks	no peaks	0	0.501	0.249	
36	4	Large peak!	Large peak!	0	0	0	
37	Note	The lab tech says the Electron probe microanalysis machine cannot look at Hydrogen, so instead she decided to lo					
38							
39	McCartys Minerals	O	Si	Fe	Mg	Ni	
40	1	peak	0.329	0.083	0.594	0.007	
41	2	no peak	0	0.008	0	0	
42							
43							

Sheet1

Olivine: $(Mg,Fe)_2Si_1O_4$

39	McCartys Minerals	O	Si	Fe	Mg	Ni
40	1	peak	0.329	0.083	0.594	0.007
41	2	no peak	0	0.008	0	0

$$Mg_{0.594}Fe_{0.083}Ni_{0.007}Si_{0.329}O_{?????}$$

Olivine: $(Mg,Fe)_2Si_1O_4$

39	McCartys Minerals	O	Si	Fe	Mg	Ni
40	1	peak	0.329	0.083	0.594	0.007
41	2	no peak	0	0.008	0	0

$$Mg_{0.594}Fe_{0.083}Ni_{0.007}Si_{0.329}O_{?????}$$

Really want Si to be close to 1 (not 0.329)
Because if Si is close to 1, then O can be set to 4

$$\frac{\text{(What I want it to be)}}{\text{(What it is)}} = \text{(Times I need to multiply it by)}$$

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Because if Si is close to 1, then O can be set to 4

$$\frac{\text{(What I want it to be)}}{\text{(What it is)}} = \text{(Times I need to multiply it by)}$$

$$\frac{1}{0.329} = 3.039$$

Olivine: $(Mg,Fe)_2Si_1O_4$

39	McCartys Minerals	O	Si	Fe	Mg	Ni
40	1	peak	0.329	0.083	0.594	0.007
41	2	no peak	0	0.008	0	0

$$Mg_{(0.594 \times 3)} Fe_{(0.083 \times 3)} Ni_{(0.007 \times 3)} Si_{(0.329 \times 3)} O_{?????}$$

$$Mg_{1.782} Fe_{0.249} Ni_{0.021} Si_{0.987} O_{?????}$$

Si ≈ 1, so O can be set to 4

$$Mg_{1.782} Fe_{0.249} Ni_{0.021} Si_{0.987} O_4$$

Olivine: $(Mg,Fe)_2Si_1O_4$

39	McCartys Minerals	O	Si	Fe	Mg	Ni
40	1	peak	0.329	0.083	0.594	0.007
41	2	no peak	0	0.008	0	0

$$Mg_{0.594}Fe_{0.083}Ni_{0.007}Si_{0.329}O_{?????}$$

For ever 1 x Si

I must have 4 x O

$0.329 \times 4 = 1.316$

$$Mg_{0.594}Fe_{0.083}Ni_{0.007}Si_{0.329}O_{1.316}$$

39	McCartys Minerals	O	Si	Fe	Mg	Ni
40	1	peak	0.329	0.083	0.594	0.007
41	2	no peak	0	0.008	0	0

Rice = 0

Coconut = 0

Water = 0.008

$$Rice_0 Coconut_0 Water_{0.008}$$

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40	1	peak	0.329	0.083	0.594	0.007
41	2	no peak	0	0.008	0	0

Rice = 0

Coconut = 0

Water = 0.008

$$Rice_0 Coconut_0 Water_{0.008}$$

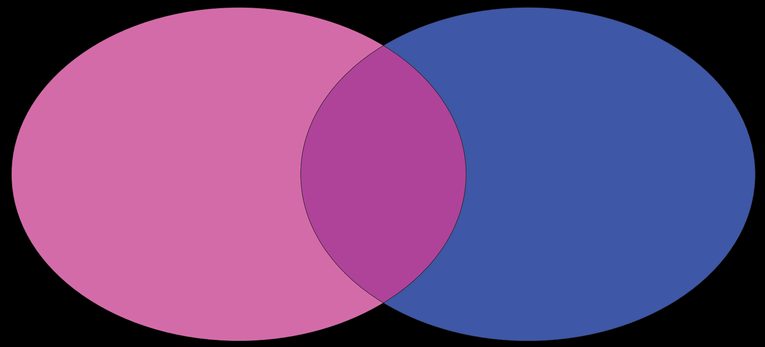
This is not coconut rice!

Minerals

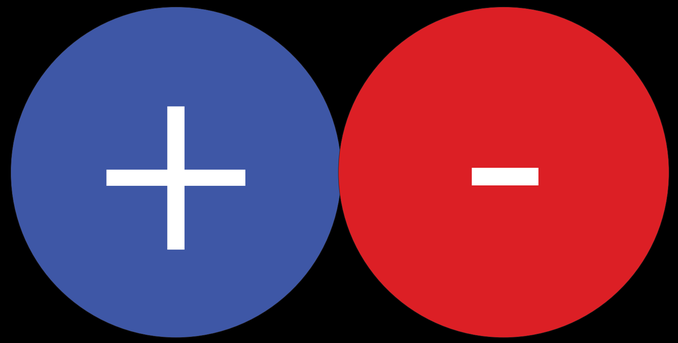
What are the types of bonding?

What are the types of bonding?

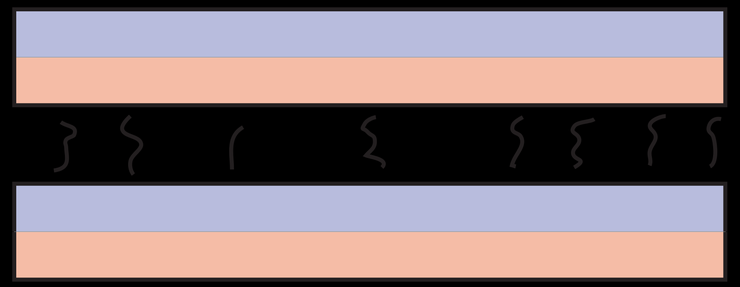
Covalent



Ionic

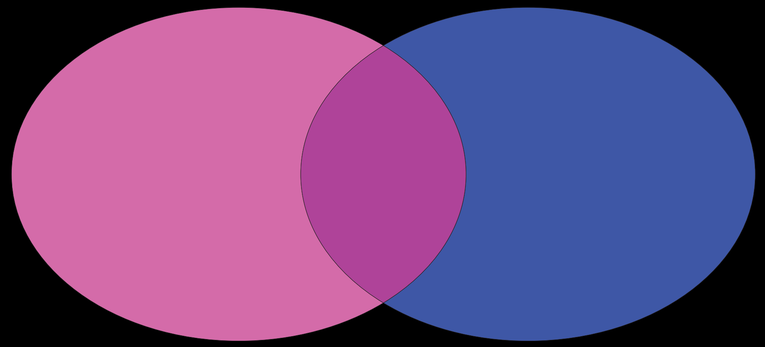


Van der Waals

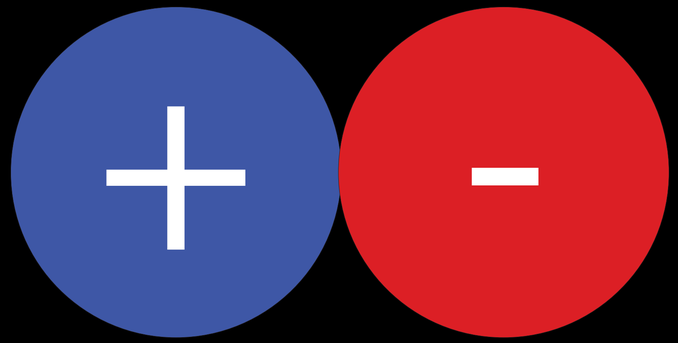


Which one is strongest?

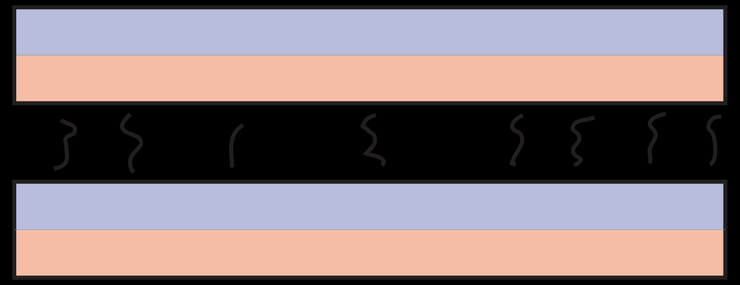
Covalent



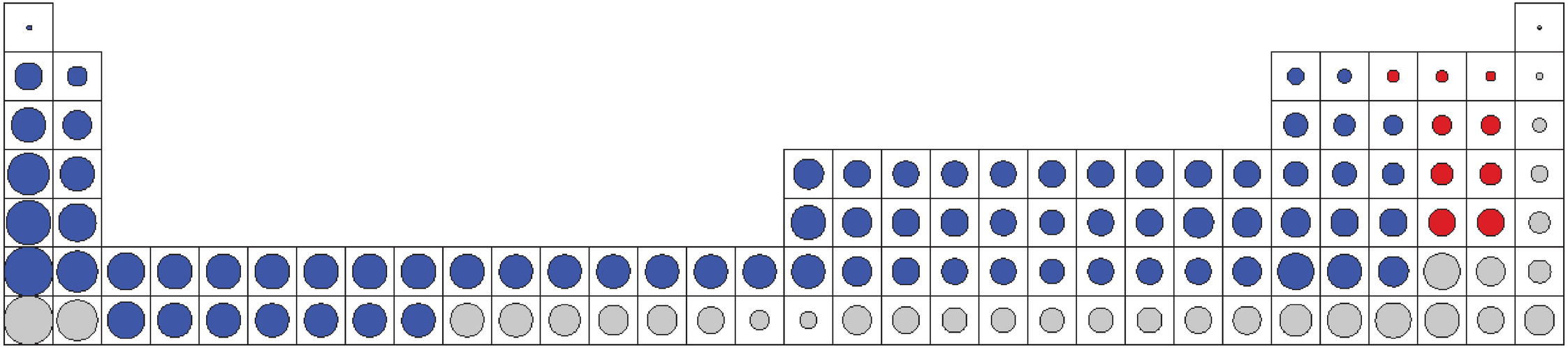
Ionic

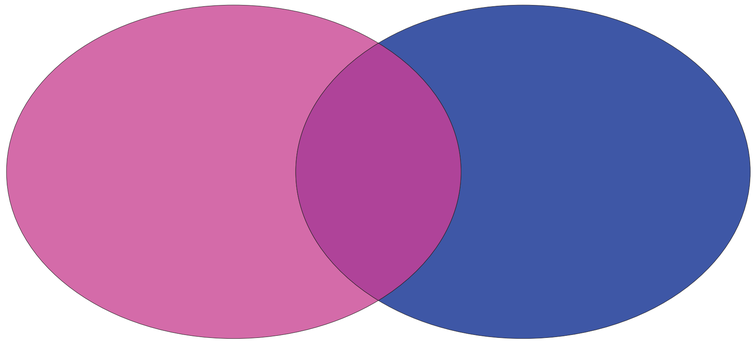


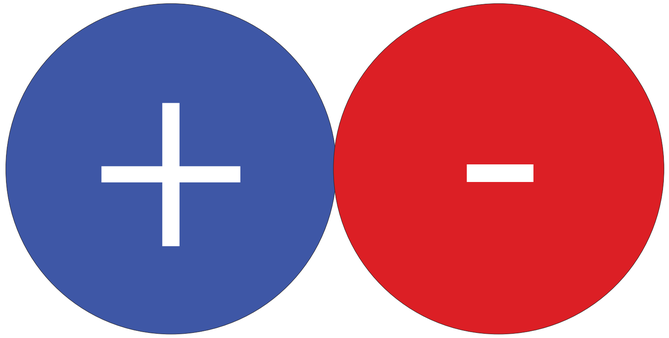
Van der Waals

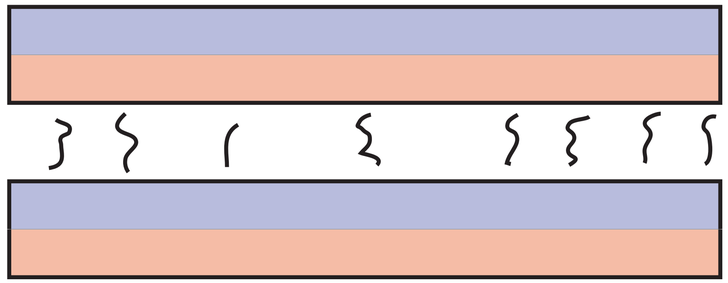


Size and bond

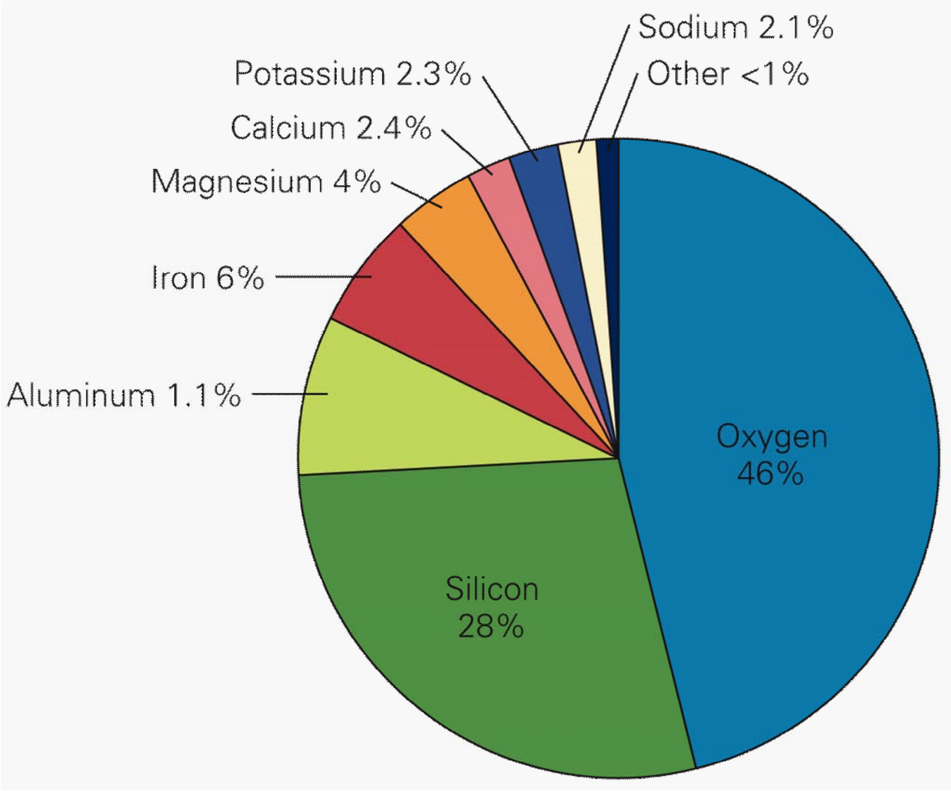








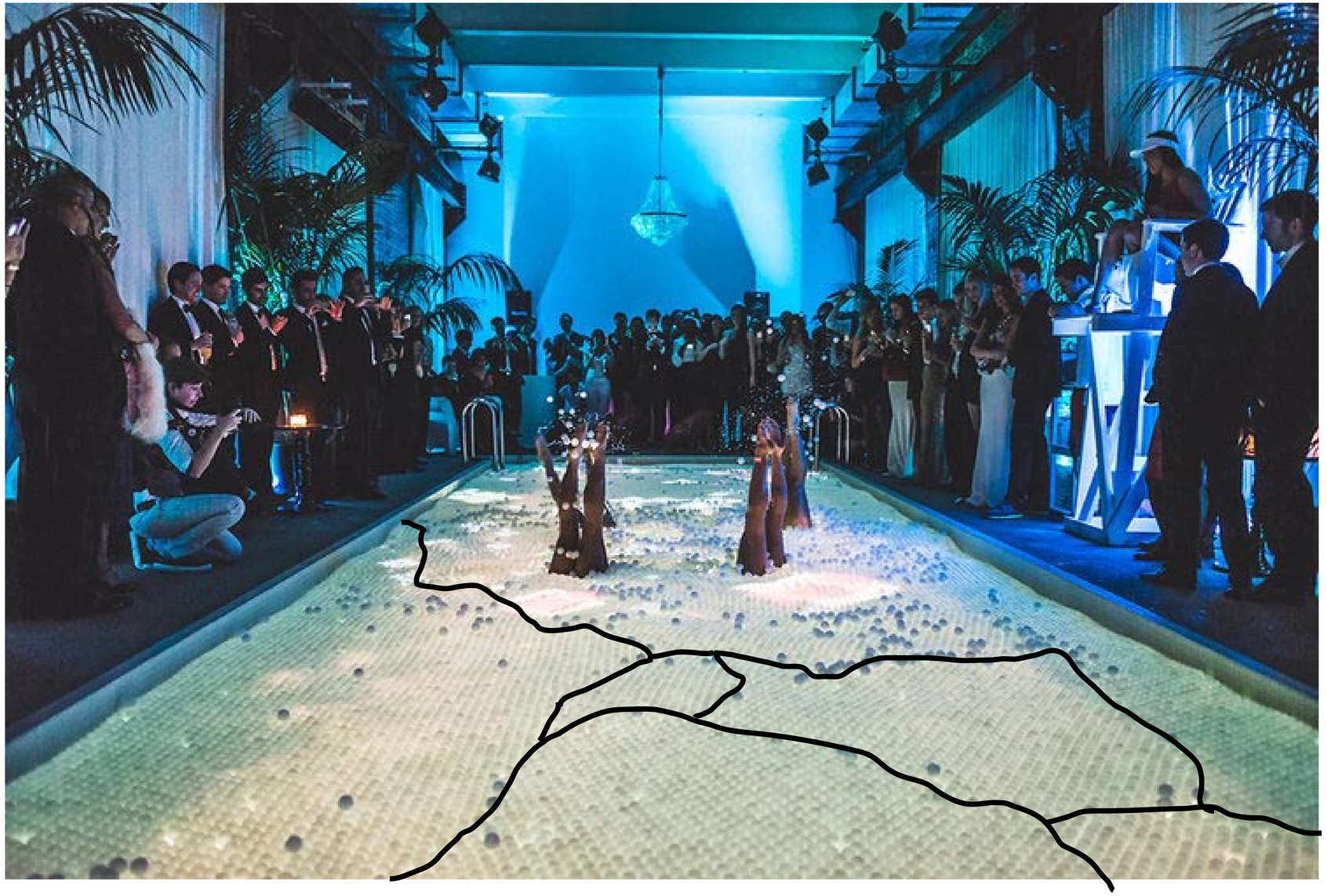
and composition



By definition a mineral is:
Naturally occurring
Inorganic
Solid
Crystalline
Ordered internal structure
Definite chemical composition

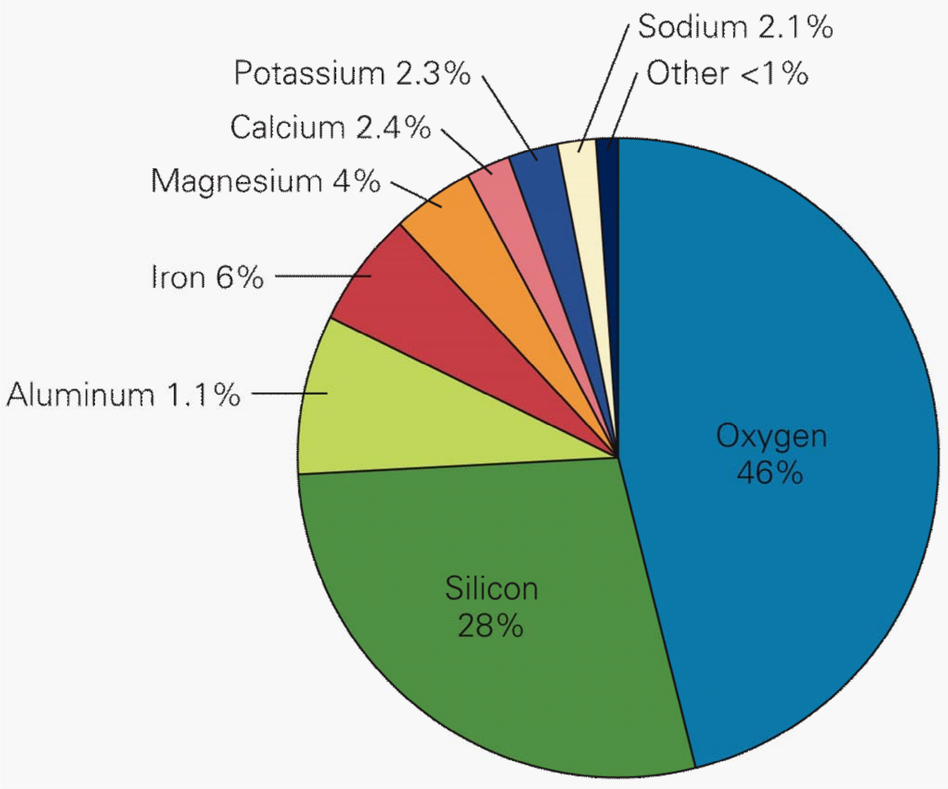
(Rock = a solid aggregate of minerals)

Ordered structure
(crystalline!)

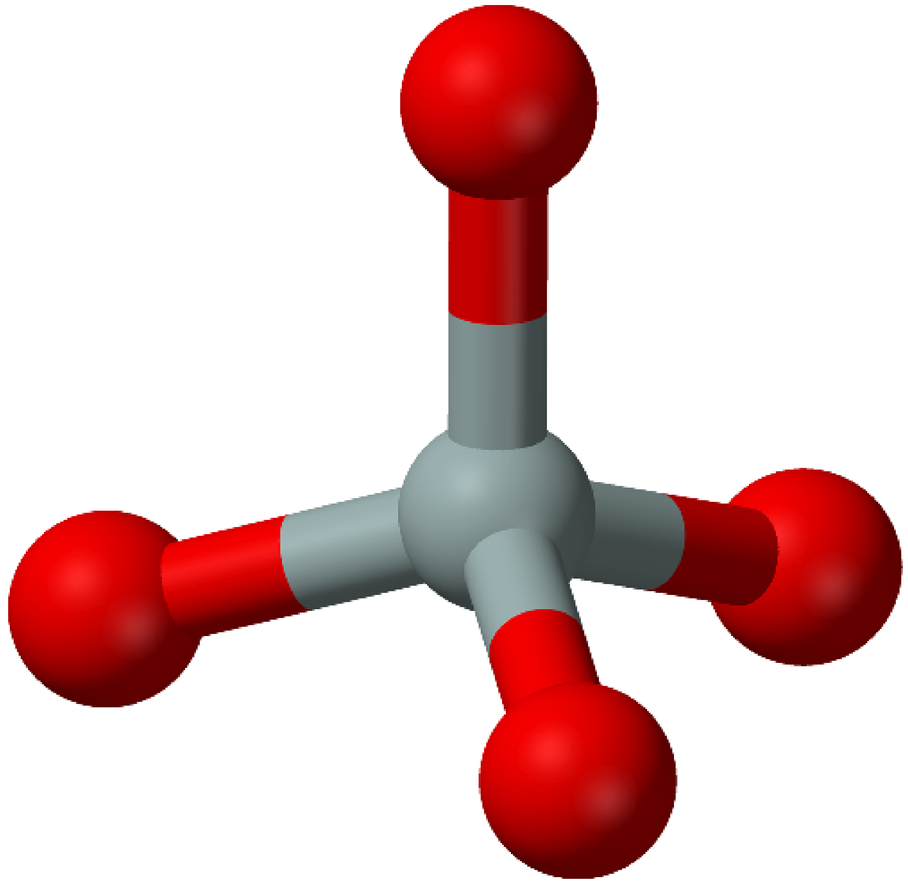


Polycrystalline Ping-Pong balls!

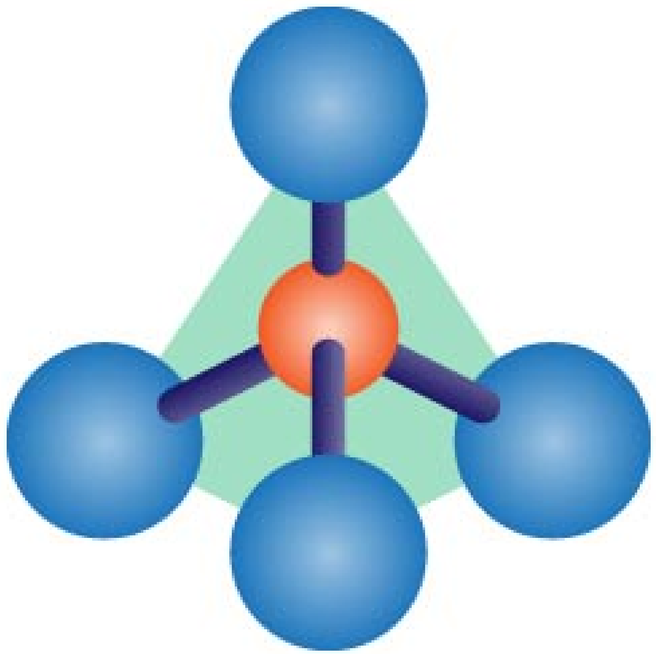
Silicon tetrahedron

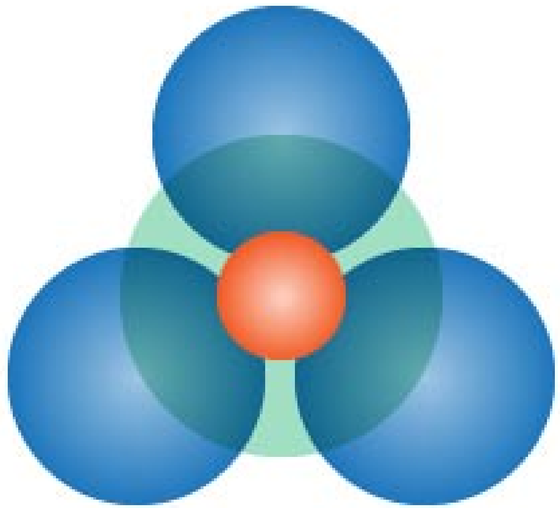


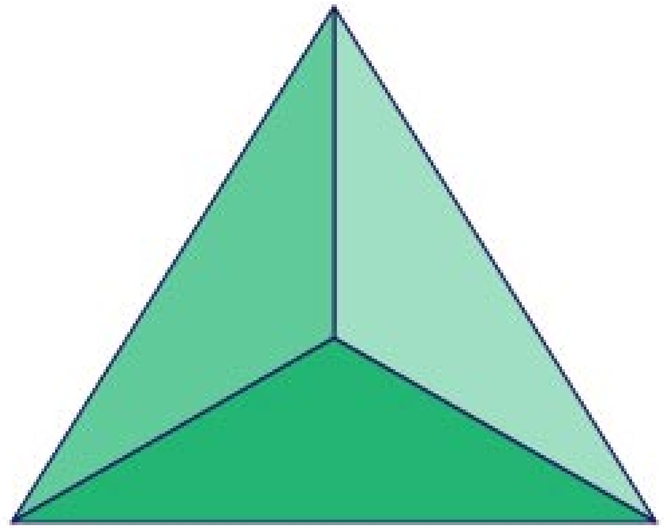
SiO_2

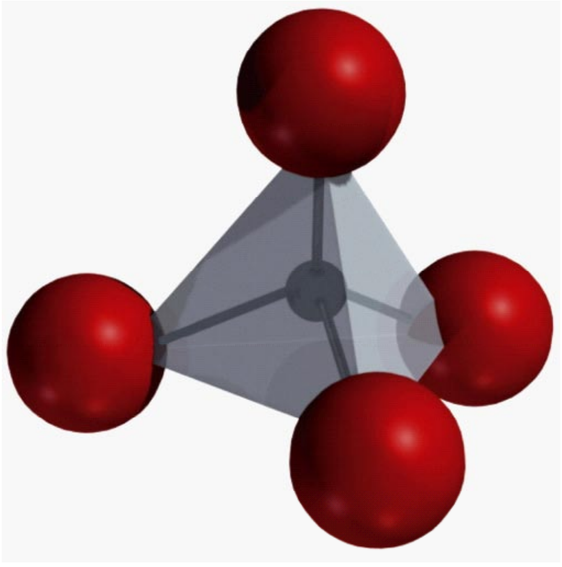


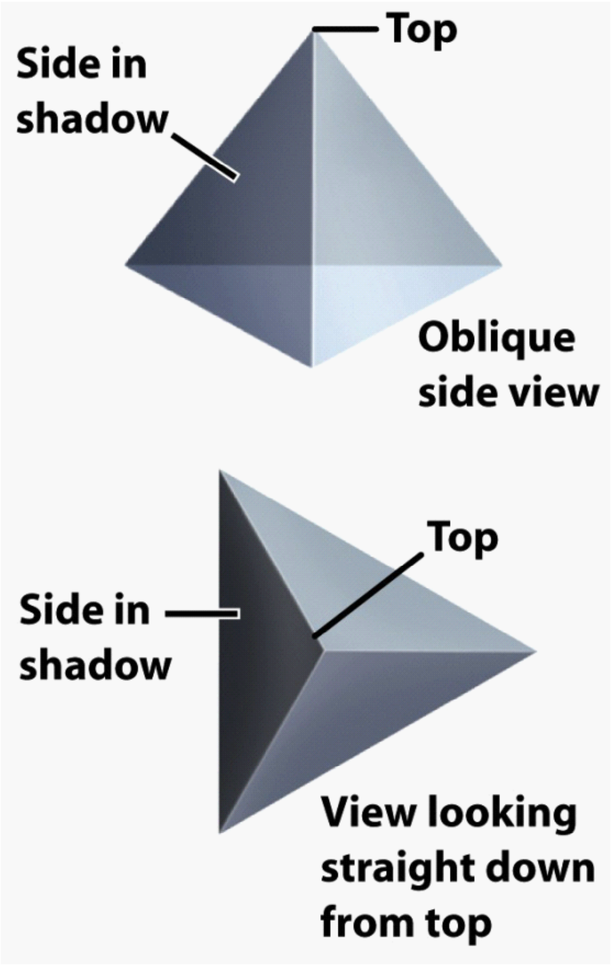
Silicon tetrahedron



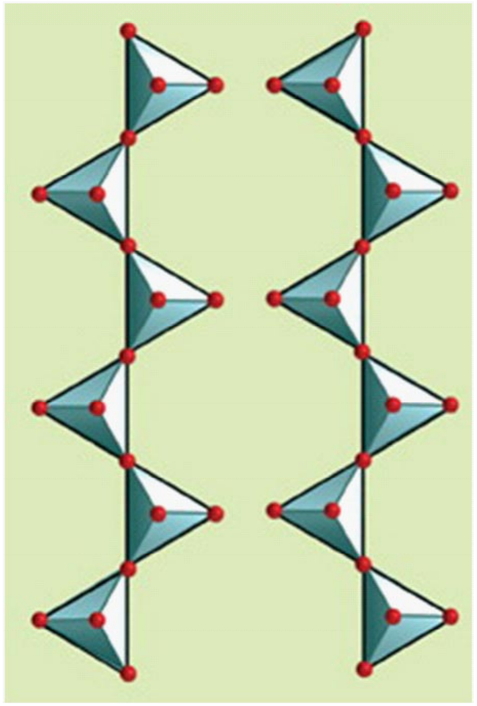


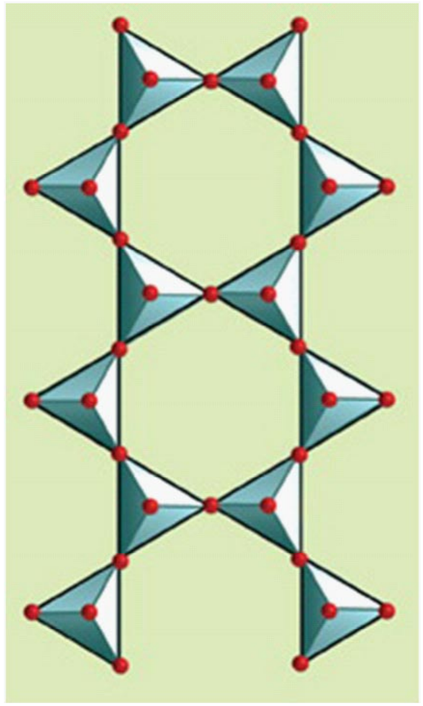


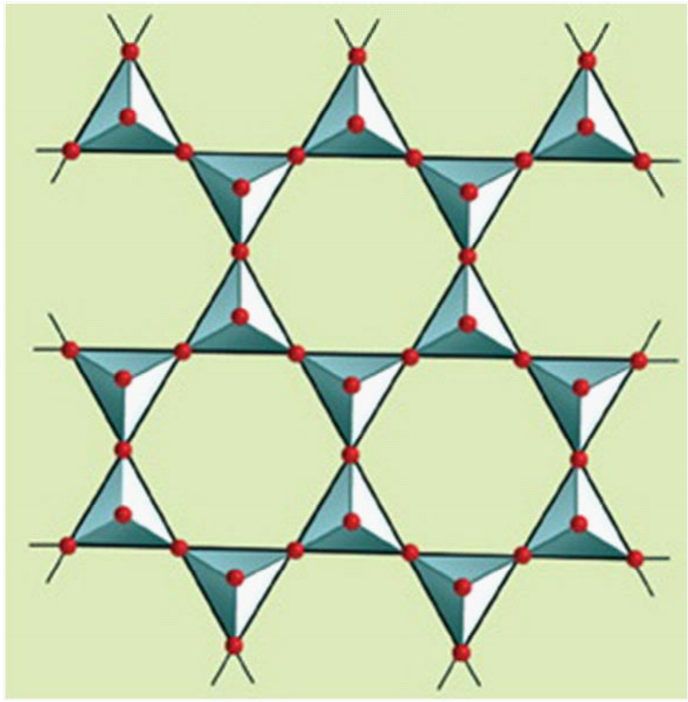


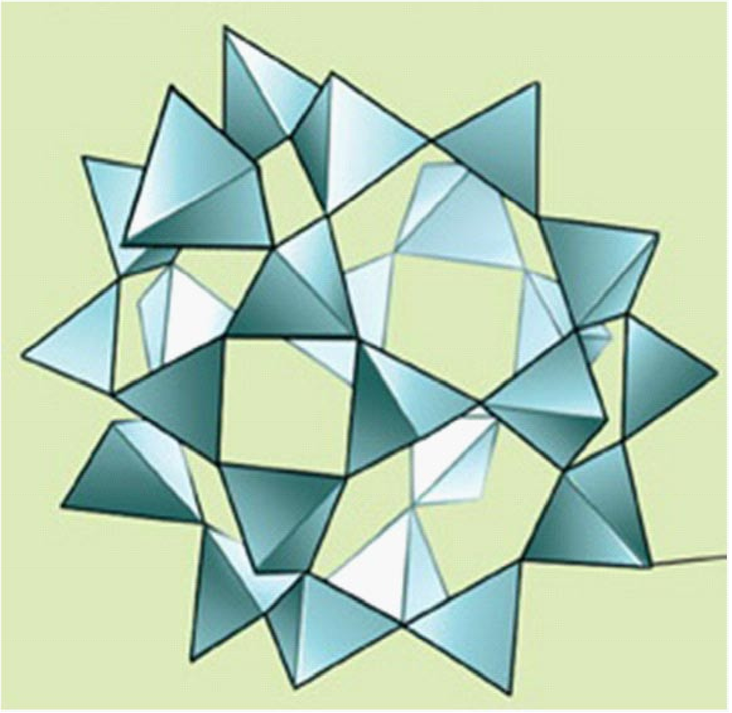

Top
Side in shadow
Oblique side view
Top
Side in shadow
View looking straight down from top

The Silicon tetrahedron is a basic building block









Minerals are classified based upon the dominant anion

Silicates	SiO_4^{4-}	Rock-forming minerals
Oxides	O^{2-}	Magnetite, Hematite
Sulfides	S^-	Pyrite, Galena
Sulfates	SO_4^{2-}	Gypsum
Halides	Cl^- or F^-	Fluorite, Halite
Carbonates	CO_3^{2-}	Calcite, Dolomite
Native elements	Cu, Au, C	Copper, Gold, Graphite

Carbonates

Primary constituents in limestone and dolostone

Calcite ($CaCO_3$) and dolomite $CaMg(CO_3)_2$ are the two most important carbonate minerals

Many non-silicate minerals have economic value

Examples

Hematite (iron oxide mined for iron ore)

Halite (halide mined for salt)

Sphalerite (sulfide mined for zinc ore)

Native copper (native element mined for copper)

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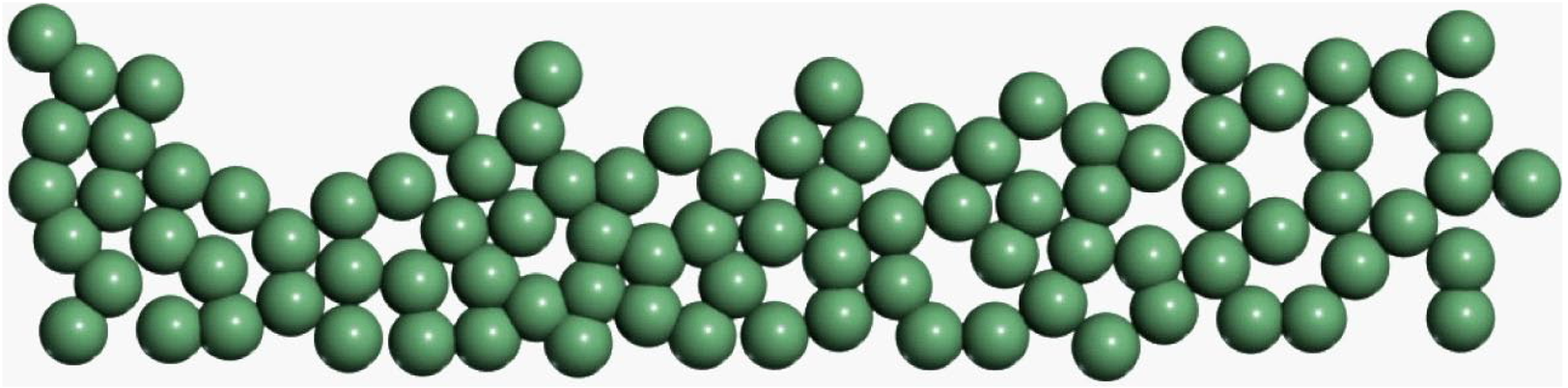
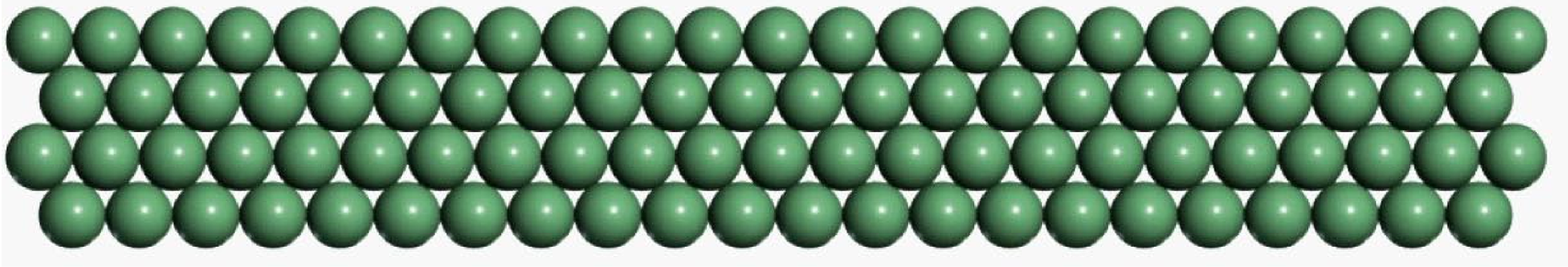
Definite chemical composition

(Rock = a solid aggregate of minerals)

Ordered?





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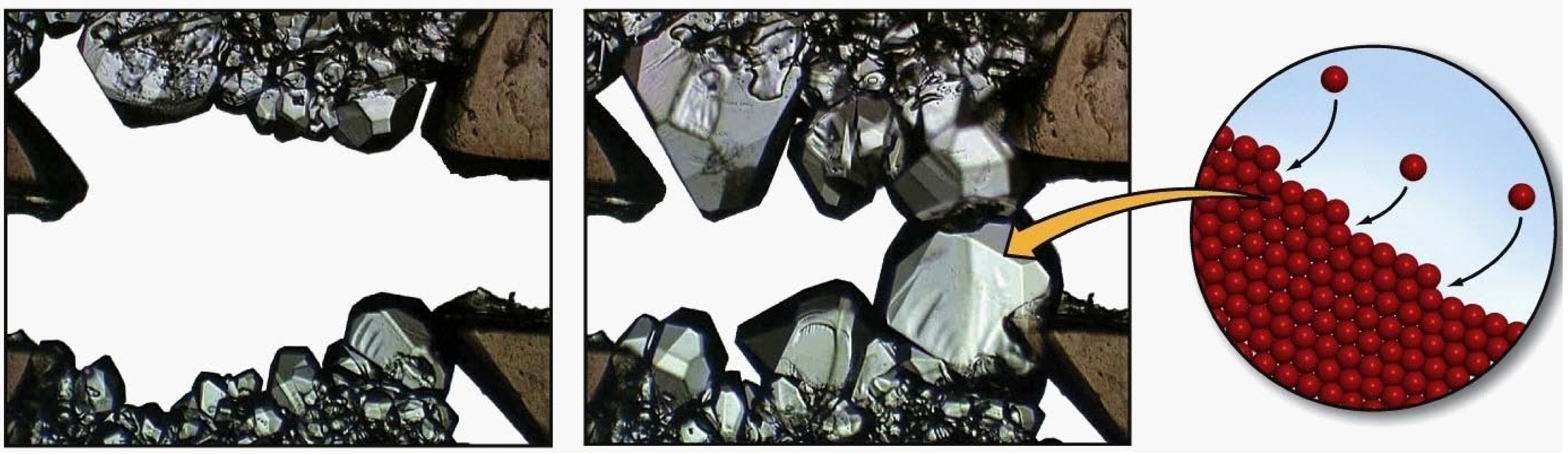
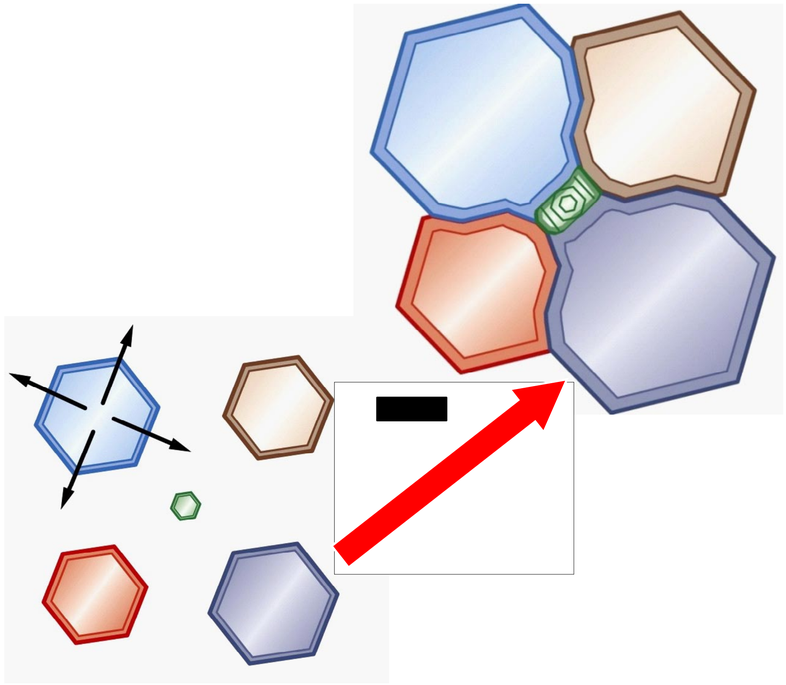
Type of Silicate Structure	Formula	Si:O Ratio
Independent Tetrahedra	SiO_4	0.25
Double Tetrahedra	Si_2O_7	0.29
Ring Silicates	Si_6O_{18}	0.33
Single Chains	SiO_3	0.33
Double Chains	Si_4O_{11}	0.36
Sheet Silicates	Si_2O_5	0.40
Framework Silicates	SiO_2	0.50

Crystal growth
(Adding layer by layer)





Outward crystal growth fills available space

Often the resulting crystal shape is governed by surroundings

Open space – Good crystal faces grow

Confined space – No crystal faces

Crystals grow by…
Solidification from a melt
Precipitation from solution
Solid-state diffusion
Bio-mineralization
Precipitate from a gas

Crystal structure and chemical composition give each mineral a unique set of physical properties

Properties that are useful in identification:

Lustre (metallic/non-metallic)

Streak (colour of mineral as powder)

Hardness (resistance of mineral to scratching)

Specific gravity (density)

Cleavage/Fracture (tendency to break along planes)

Crystal shape

Others e.g. Magnetism, reaction to hydrochloric acid, malleability, taste, smell, elasticity

Color

Be sure to be picking a good property to test for:

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