Organizational Principles of the Cosmos

THIS CRUISE:

Ben: Particles and forces
Chris: Stars and planets
Robert S.: Mind and brain
Ken: Societies and culture
Organizational Principles of the Cosmos

FOUR FORCES:
Gravity, Electromagnetism,
Strong Force, Weak Force
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MATTER:
Quarks and leptons
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ENERGY:
Some configurations of matter are more likely (i.e., have lower energy) than others.
Organizational Principles of the Cosmos

EVOLUTION:
Emergent complexity arises as selection operates on systems of many interacting particles.
What is an atom?

A very small object that has:

- At least one proton
- At least one electron
Niels Bohr’s Model of the Atom
Niels Bohr’s Model of the Atom

Electrons occur in fixed energy levels (shells)
Niels Bohr’s Model of the Atom
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Niels Bohr’s Model of the Atom
Electrons occur in fixed energy levels (shells)
Quantum Mechanics

- At the scale of atoms, everything comes in “quanta” (bundles).
- At the scale of atoms, you can’t measure a property without changing the object that you are trying to measure.
Niels Bohr’s Model of the Atom
Electrons occur in fixed energy levels (shells)
Three Rules of Electrons in Atoms

1. Each electron can exist in a number of different states.

2. No two electrons can occupy the same state in one atom.

3. Some combinations of electrons have lower energies than others.
Chemical Bonding

Key Idea: Atoms link together by the rearrangement of their electrons

1. “Magic” numbers of electrons (i.e. 2, 10, 18, or 36) form very stable atoms.

Schroedinger’s wave equation

\[-\frac{\hbar^2}{2m} \nabla^2 + V \Psi = i \hbar \frac{\partial}{\partial t} \Psi\]
Chemical Bonding

Key Idea: Atoms link together by the rearrangement of their electrons

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Chemical Bonding

Key Idea: Atoms link together by the rearrangement of their electrons.

1. “Magic” numbers of electrons (i.e. 2, 10, 18 and 36) form very stable atoms.

2. Electrons can be transferred between, or shared among, atoms to form stable chemical bonds.

3. The result is ionic, metallic, or covalent bonds.
Ionic Bonding

A sodium atom + A chloride atom

Na + Cl
Ionic Bonding

A sodium atom + A chloride atom → A sodium cation + A chloride anion

\[ \text{Na}^+ + \text{Cl}^- \]

\( \text{Na} \) and \( \text{Cl} \) represent sodium and chlorine atoms, respectively. The image illustrates the formation of sodium chloride (NaCl), which is a typical ionic compound.
Ionic Bonding

The periodic table of elements with highlighted elements.
Ionic Bonding

\[ \text{Mg} + 2\text{Cl} \]
Ionic Bonding

Mg + 2Cl → MgCl₂
Ionic Bonding

Fluorite—CaF$_2$
Ionic Bonding

Two properties of materials with ionic bonds:

1. Insulates electricity (electrons don’t move)
2. Tough but brittle
Metallic Bonding

The periodic table of elements:

- **Metallic Bonding**

![Image of periodic table with highlighted elements]
Metallic Bonding

Positive ions from the metal

Electron cloud that doesn't belong to any one metal ion
Metallic Bonding
Metallic Bonding

Three properties of materials with metallic bonds:

1. Conducts electricity (electrons free to move)
2. Malleable.
3. Shiny
Covalent Bonding

<table>
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<th>Periods</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>226.0254</td>
<td>89</td>
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The periodic table of elements.
Covalent Bonding
Covalent Bonding

H + H

H—H

Electrons

Hydrogen

Hydrogen

(a)
Covalent Bonding
Covalent Bonding
# Covalent Bonding

## Periodic Table

- **Metal**
- **Metalloid**
- **Nonmetal**

### Elements Highlighted:
- C (Carbon)

### Periods and Groups:

<table>
<thead>
<tr>
<th>Period</th>
<th>Group IA</th>
<th>Group IIA</th>
<th>Group IIIA</th>
<th>Group IVA</th>
<th>Group VA</th>
<th>Group VIA</th>
<th>Group VIIA</th>
<th>Group VIII</th>
<th>Group VA</th>
<th>Group VIA</th>
<th>Group VIIA</th>
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<td>Be (4)</td>
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<td>3</td>
<td>Na (11)</td>
<td>Mg (12)</td>
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<tr>
<td>5</td>
<td>Rb (37)</td>
<td>Sr (38)</td>
<td>Y (39)</td>
<td>Zr (40)</td>
<td>Nb (41)</td>
<td>Mo (42)</td>
<td>Tc (43)</td>
<td>Ru (44)</td>
<td>Rh (45)</td>
<td>Pd (46)</td>
<td>Ag (47)</td>
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<td>La (57)</td>
<td>Hf (58)</td>
<td>Ta (59)</td>
<td>W (60)</td>
<td>Re (61)</td>
<td>Os (62)</td>
<td>Ir (63)</td>
<td>Pt (64)</td>
<td>Au (65)</td>
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<td>Db (91)</td>
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<td>Se (93)</td>
<td>Br (94)</td>
<td>Kr (95)</td>
<td>Xe (96)</td>
<td>Rn (97)</td>
</tr>
</tbody>
</table>

### Alkali and Alkaline Earth Metals:

- Alkali Metals: Na, K, Rb, Cs
- Alkaline Earth Metals: Mg, Ca, Sr, Ba

### Halogens and Noble Gases:

- Halogens: F, Cl, Br, I, At, Rn
- Noble Gases: He, Ne, Ar, Kr, Xe, Rn

### Symbols and Atomic Numbers:

- **Ce**: 90
- **Pr**: 91
- **Nd**: 92
- **Pm**: 93
- **Sm**: 94
- **Eu**: 95
- **Gd**: 96
- **Tb**: 97
- **Dy**: 98
- **Ho**: 99
- **Er**: 100
- **Tm**: 101
- **Yb**: 102
- **Lu**: 103

### Atomic Masses:

- **He**: 4.00260
- **Ne**: 20.1797
- **Ar**: 39.9440
- **Kr**: 83.80

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**Note:** The periodic table includes elements from groups 1 to 18, highlighting the covalent bonding concept with a focus on carbon (C).
Covalent Bonding: Carbon

![Diagram of a carbon atom with four bonds]

- Atom 1
- Atom 2
- Atom 3
- Atom 4
METHANE
BUTANE
Covalent Bonding: Carbon

(a)

(b)
Properties of Materials

The properties of material arise from the kinds of atoms and how they are bonded together.
States of Matter

Solid, molecules stay rigidly in place
Gas, molecules widely spaced apart

Liquid, molecules slide past one another

Three phases of water
SOLIDS
(fixed volume and shape)

Crystal – regular atomic arrangement
SOLIDS
(fixed volume and shape)

Glass: Atoms not periodic
Glass vs. Crystal Structure
Solids: Plastics

An unbranched polymeric chain

CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂

A branched polymeric chain

CH₃

CH₂

CH₂

CH₂

CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂ – CH₂

CH₂ – CH₂ – CH₂ – CH₂

CH₂

CH₂

CH₂ – CH₂ – CH₂

CH₂ – CH₃

Plastics: Formed from chains of molecules
# Plastic Recycling

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Principal Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PET</td>
<td>The most common recycled plastic, used for food and beverage containers</td>
</tr>
<tr>
<td>2</td>
<td>HDPE</td>
<td>Rigid, narrow-neck containers for detergent and milk; grocery bags</td>
</tr>
<tr>
<td>3</td>
<td>PVC</td>
<td>Plastic pipe, outdoor furniture, sturdy containers</td>
</tr>
<tr>
<td>4</td>
<td>LDPE</td>
<td>Trash and produce bags, food storage containers</td>
</tr>
<tr>
<td>5</td>
<td>PP</td>
<td>Aerosol caps, drinking straws</td>
</tr>
<tr>
<td>6</td>
<td>PS</td>
<td>Packing peanuts, cups, and plastic tableware</td>
</tr>
</tbody>
</table>

(a) Linear polymer  
(b) Branched polymer  
(c) Cross-linked polymer
LIQUIDS

(fixed volume, variable shape)
LIQUIDS

(fixed volume, variable shape)

Liquid Crystals: Molecules line up under an electric field
GAS
(variable volume and shape)
PLASMA
(Gas with free electrons)

By far the most abundant state of matter in the universe!!!
Tensile Strength: (Strength against pulling) — 1D

- Wire
- Rope
- Chains
Compressive Strength: (Strength against squeezing)—2D

- Stack of paper
- Masonry
- Wood
Shear Strength: (Strength against twisting)-3D

- Girder network
- Diamond
Organizational Principles of the Cosmos

- Forces
- Matter
- Energy
- Evolution

We’re all trying to understand why the cosmos is the way it is.