PS-21

Physical Science in the 21st Century

Physical vs. Chemical Properties and Physical vs. Chemical Change

John Vincent

Alabama Course of Study - Science

- **Third Grade Physical Science**
- Students will:

  2. Identify physical and chemical changes of matter.

  Examples: physical—chopping wood, chemical—burning wood

Physical vs. Chemical Properties and Physical vs. Chemical Change

- This is an area of confusion to students
- This is in part because the difference between physical vs. chemical change is sometimes not obvious and sometimes none existent
- Can third graders actually comprehend the macroscale vs. atomic scale issues involved?
- Let’s look at some definitions

Types of Properties of Matter

- Physical Properties…
  - Can be observed without changing the identity or composition of a substance
    - Color, odor, density, melting point, boiling point, and hardness
- Chemical Properties…
  - Describe the way a substance may change, or react, to form other substances.
    - Flammability (ability to burn in the presence of oxygen)

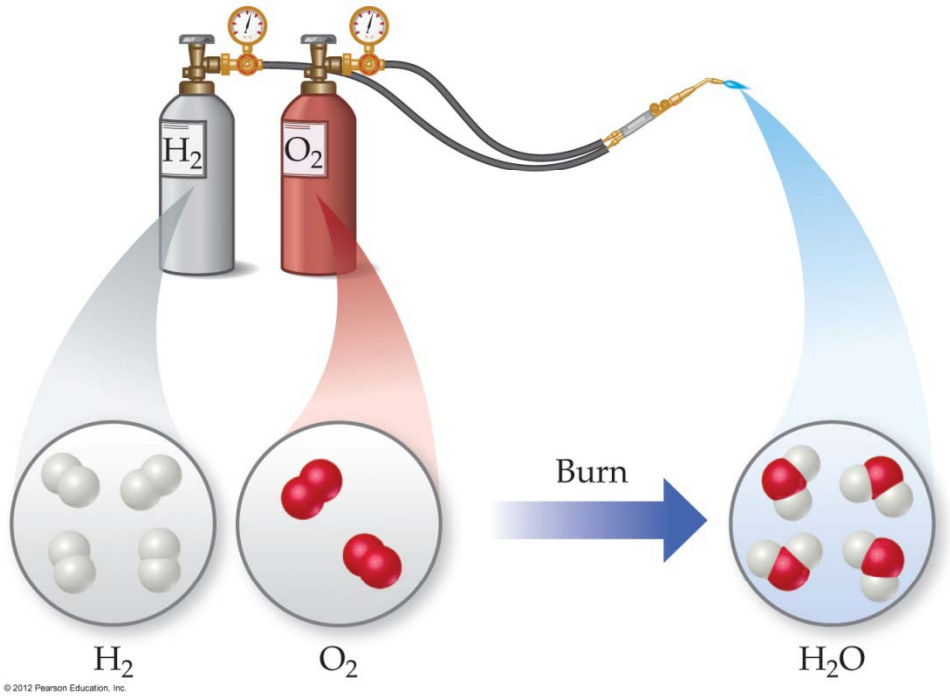
    Brown, LeMay, Bursten, & Murphy, Chemistry: The Central Science, 11th Ed., 2009 – the best selling college general chemistry textbook

Types of Changes

- Physical Changes
  - These are changes in matter that change their physical appearance but do not change the composition of a substance.
    - All changes of state
- Chemical Changes
  - A substance is transformed into a chemically different substance.
    - Combustion

Brown, LeMay, Bursten, & Murphy, Chemistry: The Central Science, 11th Ed., 2009

Chemical Reactions



In the course of a chemical reaction, the reacting substances are converted to new substances.

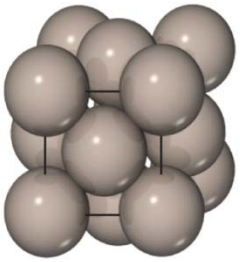
The chemical change seems clear!!! Let's look at physical changes in more detail.

Changes of State

- How clearly can we state these are physical changes?
- Are they ever chemical changes?

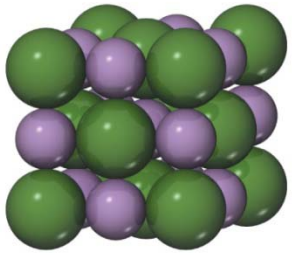
We will start by looking at bonding in solids

Bonding in Solids



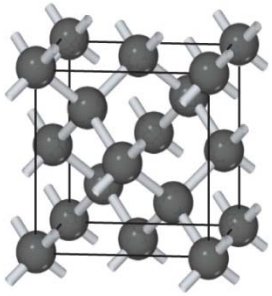
Metallic solids

Extended networks of atoms held together by metallic bonding (Cu, Fe)



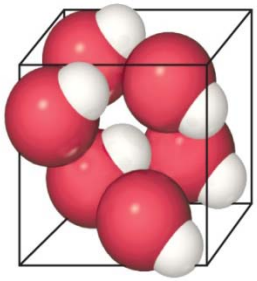
Ionic solids

Extended networks of ions held together by ion–ion interactions (NaCl, MgO)



Covalent-network solids

Extended networks of atoms held together by covalent bonds (C, Si)

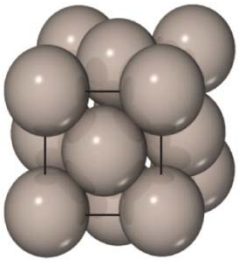


Molecular solids

Discrete molecules held together by intermolecular forces (HBr, H_2O)

- There are four general types of solids.
- **Metallic solids** share a network of highly delocalized electrons.
- **Ionic solids** are sets of cations and anions mutually attracted to one another.

Bonding in Solids



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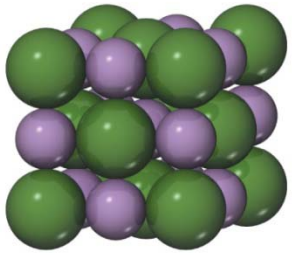

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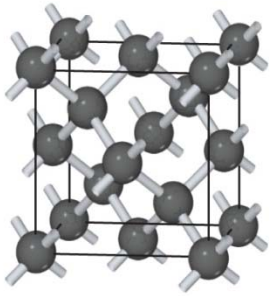
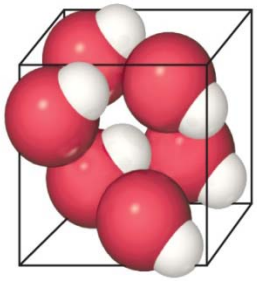


Covalent-network solids

Extended networks of atoms held together by covalent bonds (C, Si)



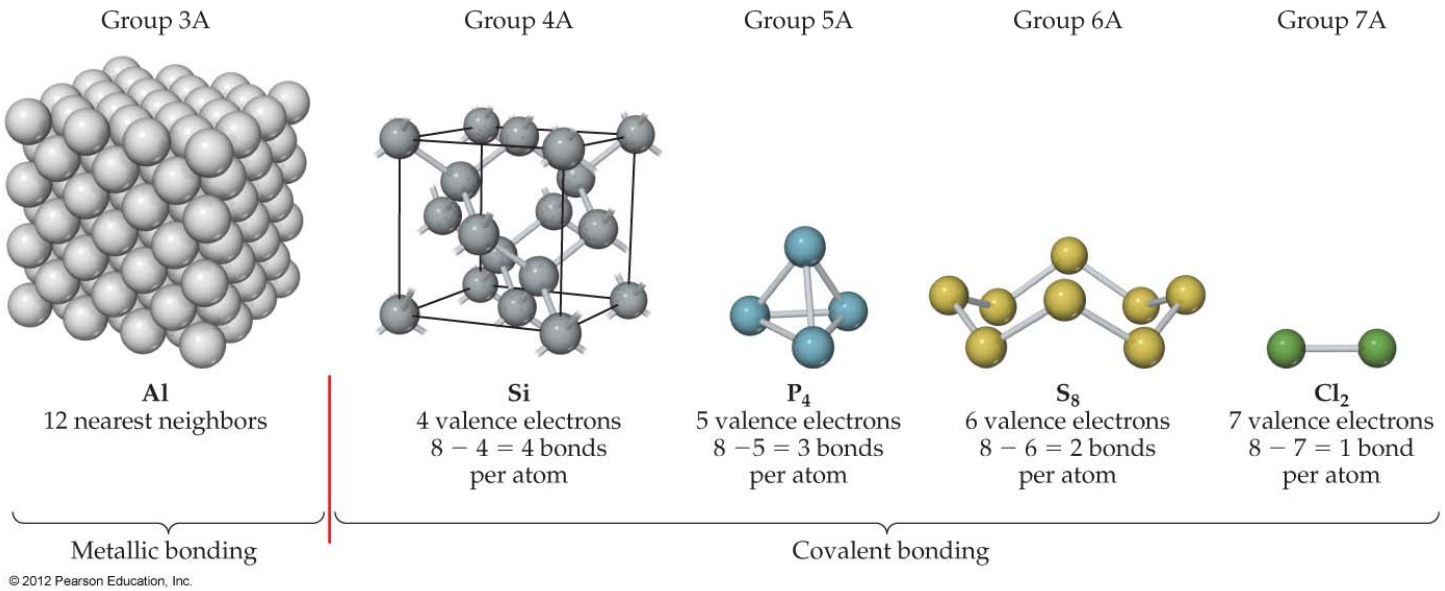
Molecular solids

Discrete molecules held together by intermolecular forces (HBr, H_2O)

- **Covalent-network solids** are joined by an extensive network of covalent bonds.
- **Molecular solids** are discrete molecules that are linked to one another only by van der Waals forces.

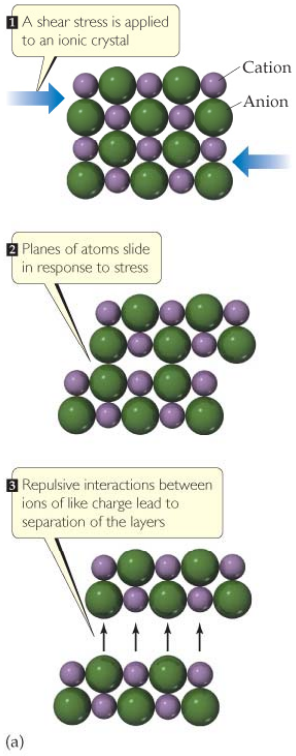
Metallic Bonding

- In elemental samples of nonmetals and metalloids, atoms generally bond to each other covalently.
- Metals, however, have a dearth of valence electrons; instead, they form large groups of atoms that share electrons among them.



Ionic Solids

- In ionic solids, the lattice comprises alternately charged ions.
- Ionic solids have very high melting and boiling points and are quintessential crystals.

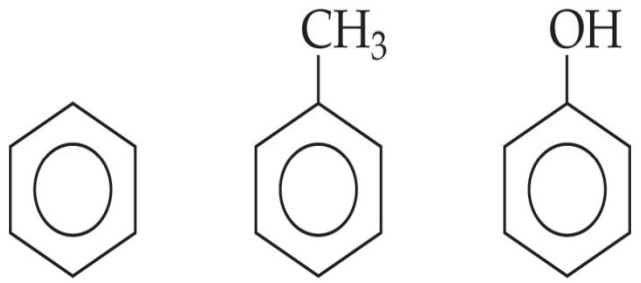


(a)

(b)

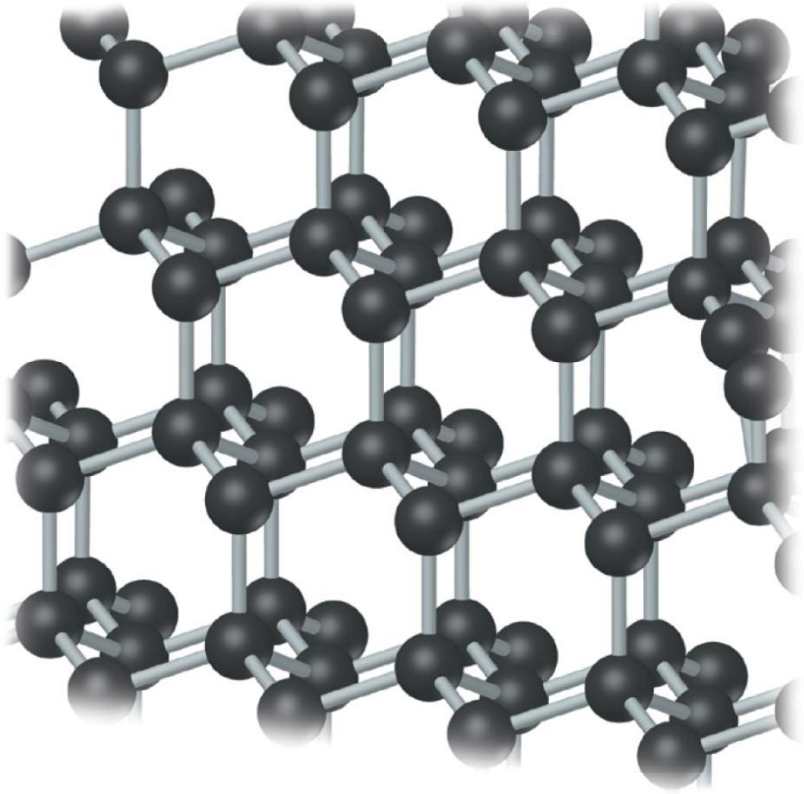
Molecular Solids

- The physical properties of molecular solids are governed by van der Waals forces.
- The individual units of these solids are discrete molecules.



	Benzene	Toluene	Phenol
Melting point (°C)	5	–95	43
Boiling point (°C)	80	111	182

Covalent-Network and Molecular Solids



(a) Diamond

- Diamonds are an example of a covalent-network solid, in which atoms are covalently bonded to each other.
  - They tend to be hard and have high melting points.

Molecular Solid – Melting and Boiling

- Must overcome a portion of intermolecular forces to get molecules to be able to move past each other to some degree from being trapped in a lattice
- Must overcome all intermolecular forces to get isolated molecules in gas phase
- The molecules maintain their chemical identity – a physical change

Other Types of Solids

- What is being overcome/broken in melting and boiling processes?
- CHEMICAL BONDS – ionic, metallic, and covalent bonds

- Are these chemicals reactions?

In the course of a chemical reaction, the reacting substances are converted to new substances.

Compare These

- $I_2(s) \rightarrow 2\ I(g)$
- No one would argue this is not a chemical reaction, breaking the I-I bond and that
- iodine atoms and iodine molecules are different chemical substances.

- $Au_x(s) \rightarrow x\ Au(g)$
- Is breaking 12 Au-Au bonds per Au atom during sublimation a chemical reaction?
- Are not gold metal, a conducting solid, and gold atoms different chemical substances?
- One atom cannot have a conductance band

Sublimation of NaCl

- Heat sodium chloride crystals so that some vapor is formed. Under a wide range of conditions of temperature and pressure, the vapor will contain significant amounts of NaCl molecules.

  $Na_xCl_x(s) \rightarrow x\ NaCl(g)$

- Gone from a single chemical entity, the ionically bonded crystal to discrete molecules
- Gone from six bonds for each Na^+ and each Cl^- to singly bonded diatomic molecule, one bond per atom.
- Chemical change???????????

Final Example - Covalent Solid

- $Si_x(s) \rightarrow xSi(g)$ (under appropriate conditions)
- Is breaking four Si-Si covalent bonds per Si atom a chemical reaction?
- Are not the semiconductor solid silicon and silicon atoms different chemical substances?
- Are not changes of state except for molecular solids chemical reactions???????

How about chopping of wood?

- Wood is a complex material. What happens when we chop?
- Let’s simplify to cutting a piece of paper, a sheet of cellulose molecules.
- Cutting a piece of paper consists of breaking chemical bonds – cutting high-molecular-weight polymers into lower-molecular-weight polymers, i.e., into different molecules – a chemical change
- While the bulk may be unaffected, chemistry is happening at the point of action

“Cutting” Gold - Color

- If one could simply cut a gold bar into smaller and smaller pieces, one would eventually generate gold nanoparticles – so small that it is impossible to have bands to conduct electrons
- If no conductance band, then no lustrous gold color
- 5 – 20 nm diameter gold nanoparticles are red (λ_{max} = 525 nm)
- Pure gold can be colors other than gold!

“Cutting” Gold – Melting Point

- “Cutting” gold into smaller pieces also affects melting point

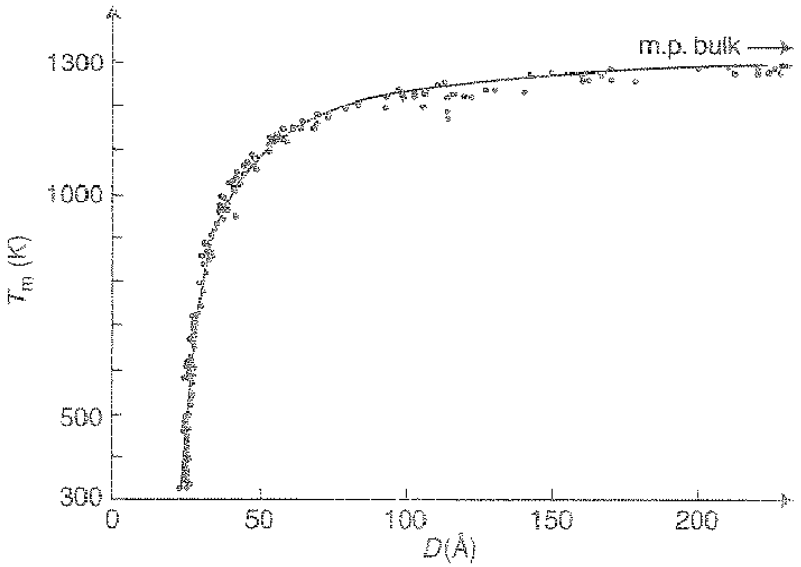


Figure 3.27. Melting point of Au nanoparticles as a function of average particle size determined by means of scanning electron-diffraction method [67].

Changes in Chemical Property with Size – Flammability of Iron

- An example of “cutting” changing a chemical property
- A 1-kg brick of iron metal is not flammable
- Ultrafine iron powder (~5 microns) is pyrophoric and can ignite spontaneously in air.
- Combustion reaction dependent on particle size – a “physical” change alters “chemical properties”???

Mixing Substances

- Consider making bronze. Most textbooks consider this a homogeneous mixture of tin (solute) in copper (solvent) – a purely physical mixture
- However, the mixture is made up of tin atoms metallically bonded to copper atoms – broke Cu-Cu metallic bonds and Sn-Sn metallic bonds to form new Cu-Sn metallic bonds – sounds like a chemical reaction
- The properties of bronze are not an average of the properties of the two metal
  - Lower melting point than either
  - Different color
  - Different thermal expansion
  - Greater hardness than either
  - Very different electrical conductivity, especially at low temperature

Summary

- Explaining the difference between physical and chemical to a third grader (or student of any age) is an exercise in futility
- The concept of physical versus chemical properties and physical versus chemical change are from the 19^{th} century, prior to the development of the modern atomic theory
- What happens in “physical” or “chemical” processes is best explained in terms of what happens to the molecules, atoms, and ions at the atomic level with reference to how this relates to macroscopic properties

Prediction

- The concept of physical versus chemical properties and physical versus chemical change will be disappearing from general chemistry textbook and hopefully some day from textbooks for K-12