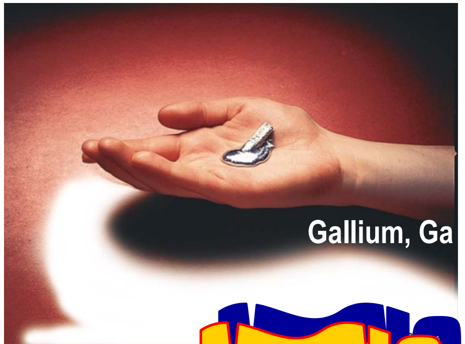
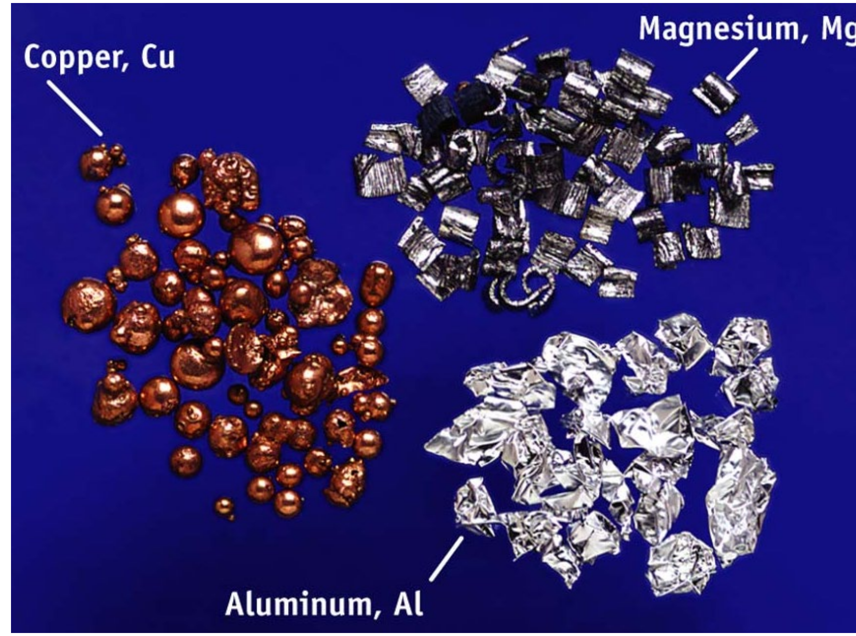


METALS



CHEMISTRY 1000

Topic #2: The Chemical Alphabet

Fall 2020

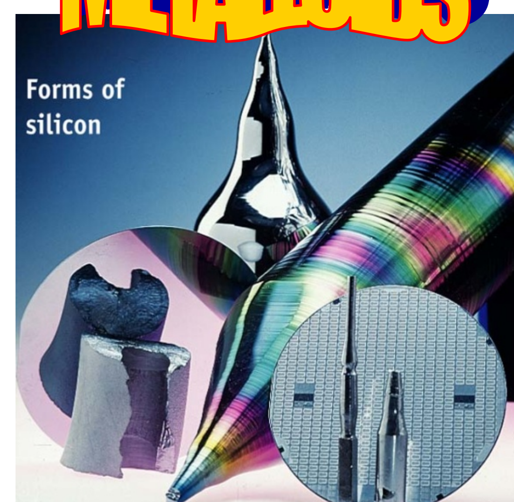
Dr. Susan Findlay

See Exercises 11.1 to 11.4

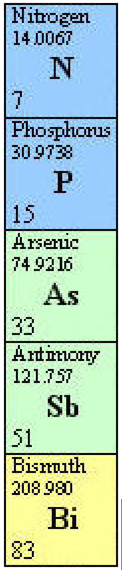
NONMETALS

Forms of Carbon

METALLOIDS



The Group 15 Elements

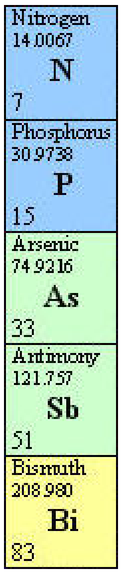


- What do we know about the Group 15 elements?
  - N is diatomic; P, As and Sb have multiple allotropes
  - Nonmetal (N, P), metalloid (As, Sb) or metal (Bi)
  - They form one monoatomic anion (-3)
  - Sb^{3+} and Bi^{3+} also exist
  - They have five valence electrons (valence electron configuration $[N.G.]ns^2np^3$) and positive electron affinities

	Melting Point	Boiling Point	State (at 20 °C)	Density (at 20 °C)
Nitrogen	-210 °C	-196 °C	Gas	0.00125 g/cm^3
Phosphorus (white)	44 °C	280.5 °C	Solid	2.2 g/cm^3
Arsenic (grey)	817 °C*	616 °C*	Solid	5.78 g/cm^3
Antimony (grey)	631 °C	1635 °C	Solid	6.69 g/cm^3
Bismuth	271 °C	1580 °C	Solid	9.75 g/cm^3

Images from http://www.theodoregray.com/PeriodicTableDisplay/

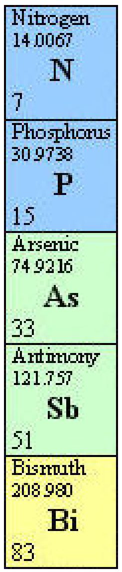
Nitrogen



- Nitrogen is a very stable diatomic molecule (N_2).
  - The triple bond holding the two atoms together is very strong, so N_2 is a very unreactive gas.
  - Nitrogen is often used as an inert atmosphere for chemical reactions and for production of electronic components. Being the major component of air, it is much cheaper than the most common alternative, argon. *(Air is 78% N_2, 21% O_2 and 1% Ar with traces of many other gases.)*

- As we saw earlier in the course, nitrogen will react spontaneously with lithium and with the alkaline earth metals:

Nitrogen



- The reaction between nitrogen and hydrogen is exothermic, but the activation energy is high, so it will not proceed without some sort of catalyst. Why?

- Nitrogen is an essential element for all organisms, but most cannot use elemental nitrogen (N_2), instead requiring nitrogen that has been "fixed" in some way (as a nitrate, an ammonium salt or as part of a biological molecule).

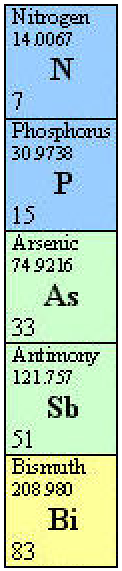
- Some microorganisms can "fix" nitrogen by making NH_3 from N_2, H^+ and e^-.

Nitrogen

Nitrogen 14.0067 **N** 7
Phosphorus 30.9738 **P** 15
Arsenic 74.9216 **As** 33
Antimony 121.757 **Sb** 51
Bismuth 208.980 **Bi** 83

- The most important method for producing ammonia (NH_3) industrially is the Haber-Bosch process.
  - Nitrogen and hydrogen are reacted in the presence of catalyst at a high temperature ($400\ ℃$) and high pressure (~200 bar):
  - The reaction is forced to continue in a forward direction by removing ammonia as it is produced by cooling it to a liquid. NH_3 condenses at a much higher temperature than N_2 or H_2. Why?
  - The unreacted nitrogen and hydrogen are recycled back into the reaction chamber, allowing for almost 100% yield of NH_3 over time.

Nitrogen


Nitrogen
14.0067
N
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Phosphorus
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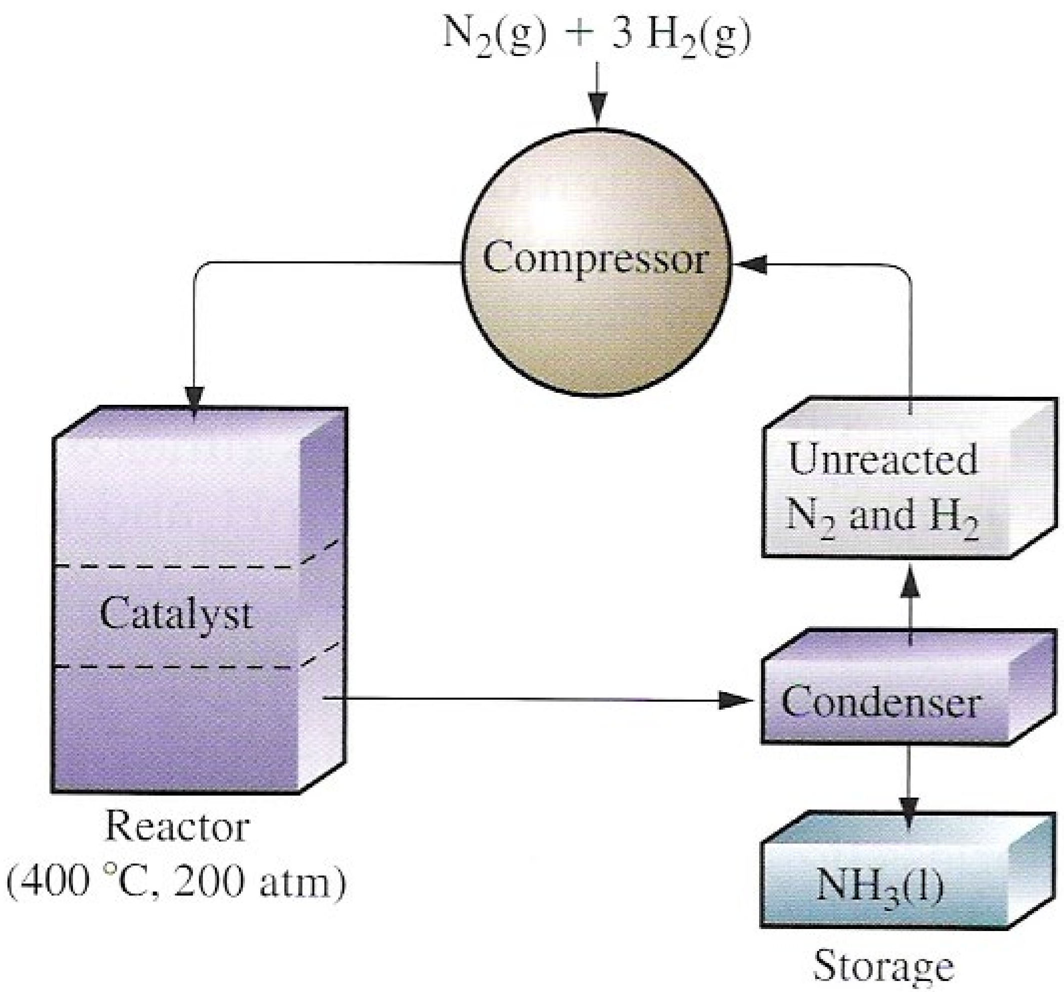
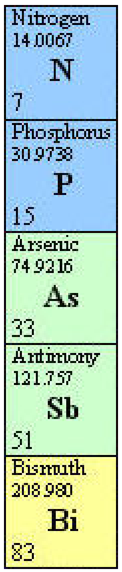

$N_2(g) + 3\,H_2(g)$
Compressor
Unreacted
N_2 and H_2
Catalyst
Condenser
$NH_3(l)$
Reactor
(400 °C, 200 atm)
Storage

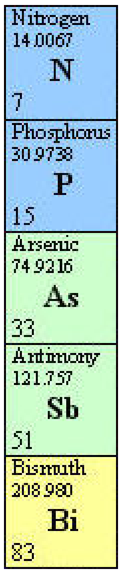
Nitrogen



- Ammonia is a weak base. When it dissolves in water, some of the ammonia reacts with the water:

- For this reason, aqueous ammonia ($NH_{3(aq)}$) is often referred to as ammonium hydroxide ($NH_4OH_{(aq)}$). Since this equilibrium is reactant-favoured, $NH_{3(aq)}$ is more descriptive of the solution.

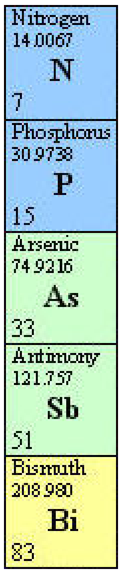
Nitrogen



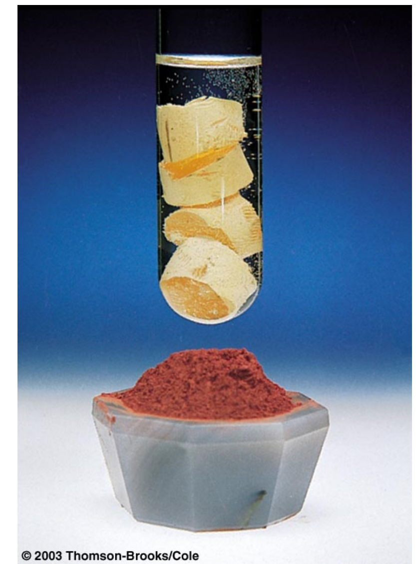
- Ammonia reacts completely with strong acids. It should be kept well away from nitric acid as the product of that reaction is highly explosive! What is this product? Write a balanced equation for the reaction between ammonia and nitric acid.

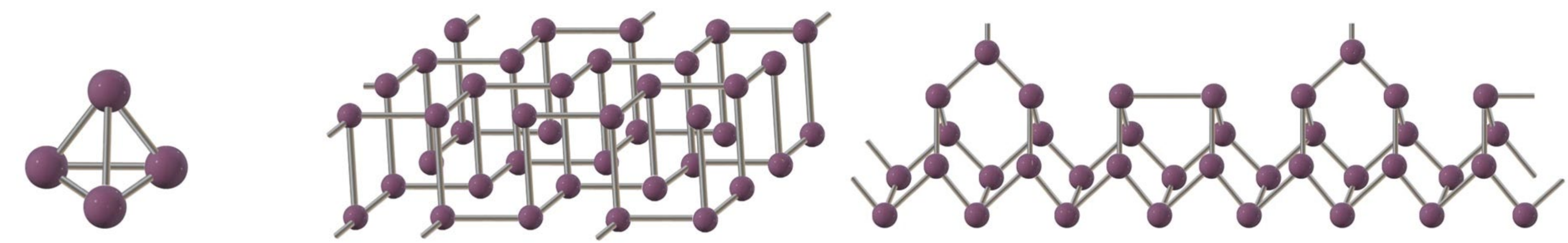
- Many other explosive compounds contain nitrogen because N_2 is a gas containing very strong bonds so reactions producing it tend to release a lot of energy. e.g. azides (N_3^- salts), TNT

Phosphorus



- There are two major allotropes of phosphorus:
  - White phosphorus (P_4) is soft and waxy and so reactive with air that it is stored under water. It can ignite spontaneously in air
  - Red phosphorus (P, a **network solid**) is formed when white phosphorus is heated to 200 - 400 ^{o}C away from air.
  - Black phosphorus and violet phosphorus also exist. They are both network solids.





(a) White phosphorus (b) Black phosphorus (c) Red phosphorus

Phosphorus

Nitrogen	14.0067	N	7
Phosphorus	30.9738	P	15
Arsenic	74.9216	As	33
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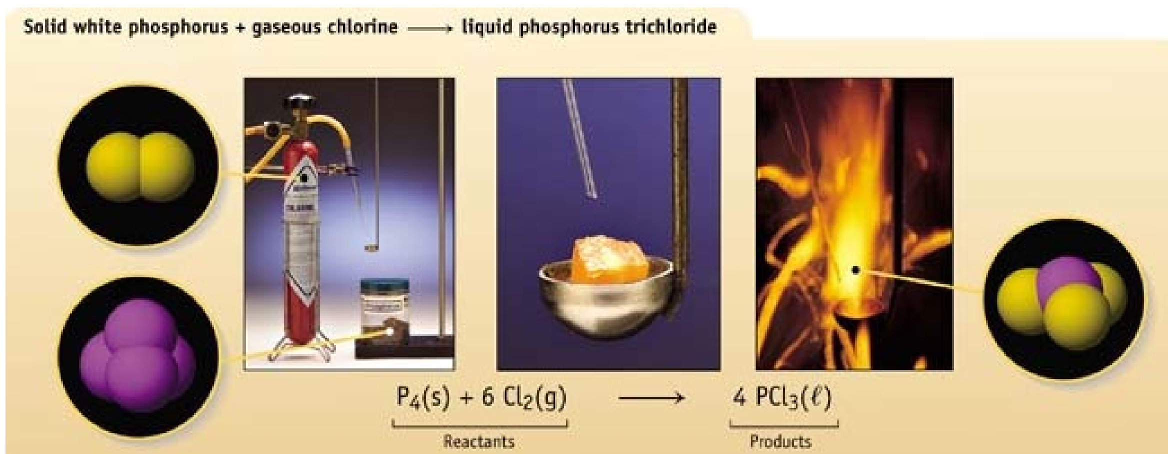
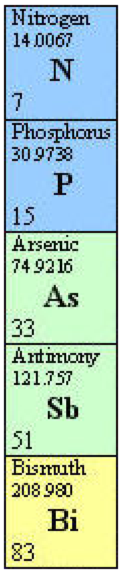
- As we saw in the Halogens section, phosphorus reacts with halogens to make PX_3 or PX_5 (depends on amount of halogen).



- It isn't surprising that P_4 is so reactive given its structure. Compare the bond angles in P_4 to the ideal bond angles for an atom with a steric number of 4 (three bonds plus one lone pair).

Phosphorus

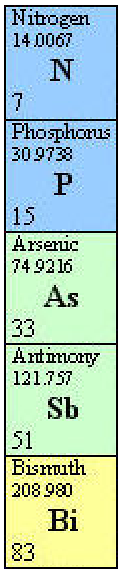


- Phosphorus forms strong bonds with oxygen, and there are several phosphorus oxides, phosphates, phosphites and phosphoric acids.

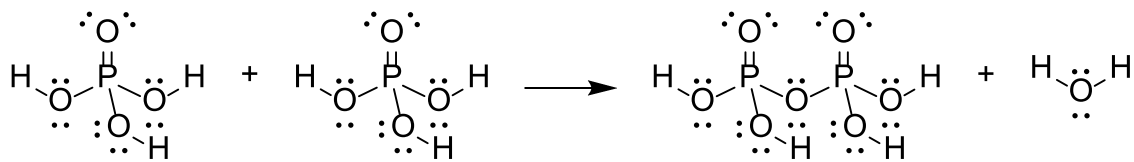
- We saw that the sulfur oxides were acidic. This can be generalized to all nonmetal oxides. The two main oxides of phosphorus are P_4O_6 and P_4O_{10}. What is formed when each reacts with water?

Do you remember what was unusual about phosphorous acid?

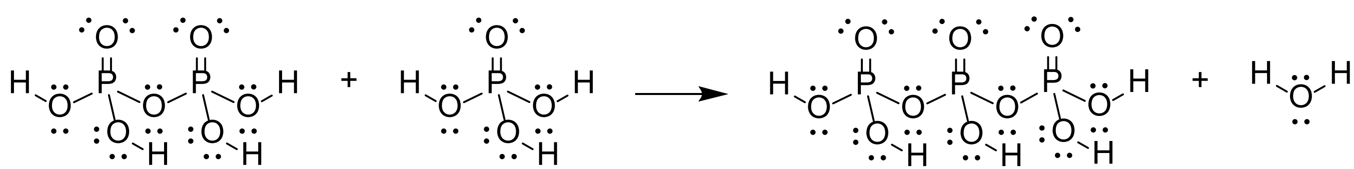
Phosphorus



- Phosphoric acid is unusual among the oxoacids in that it has a tendency to polymerize.
  - H_3PO_4 can also be called "orthophosphoric acid"
  - When two molecules of H_3PO_4 combine, they make "diphosphoric acid" (or "pyrophosphoric acid") and a molecule of water:



  - If a third molecule of H_3PO_4 is added to the chain, "triphosphoric acid" is produced:



- Two very important biological molecules (ATP and ADP) contain derivatives of these polymerized phosphoric acids.