8. Chemistry of the Main Group Elements

A Snapshot on Main Group Chemistry

unusual bonding, structure & reactivity

gold(I) methanium
H. Schmidbaur et al.
Chem. Ber. 1992

{Ba-cryptand}⁺ disodide²⁻
M.Y. Redko et al., JACS 2003

also, in NH₃(I)
Na⁺ (NH₃)₂e⁻
8. Chemistry of the Main Group Elements

A Snapshot on Main Group Chemistry

very powerful reducing agent

Na\(_2\)\(^2\)−

gold(I) methanium
H. Schmidbaur & F. Gabbai

also, in NH\(_3\)(I)
Na\(^+\) (NH\(_3\))\(e^-\)

M.Y. Redko et al., JACS 2003

8. Chemistry of the Main Group Elements

here we go again...
table salt #1

...well, not in my book!

Check out Nitrogenase or Cytochrome C-Oxidase...or Hemoglobin...

<table>
<thead>
<tr>
<th>Rank</th>
<th>Chemical</th>
<th>Production (\times 10^6) lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sodium chloride, NaCl</td>
<td>45.1</td>
</tr>
<tr>
<td>2</td>
<td>Sulfuric acid, H(_2)SO(_4)</td>
<td>36.3</td>
</tr>
<tr>
<td>3</td>
<td>Phosphoric acid, H(_3)PO(_4)</td>
<td>32.2</td>
</tr>
<tr>
<td>4</td>
<td>Nitrogen, N(_2)</td>
<td>29.4</td>
</tr>
<tr>
<td>5</td>
<td>Ethylene, H(_2)C═CH(_2)</td>
<td>22.8</td>
</tr>
<tr>
<td>6</td>
<td>Oxygen, O(_2)</td>
<td>21.2</td>
</tr>
<tr>
<td>7</td>
<td>Lactic, C(_3)OH</td>
<td>18.1</td>
</tr>
<tr>
<td>8</td>
<td>Propylene, H(_2)C═CH—CH(_2)</td>
<td>13.1</td>
</tr>
<tr>
<td>9</td>
<td>Ammonia, NH(_3)</td>
<td>11.9</td>
</tr>
<tr>
<td>10</td>
<td>Chlorine, Cl(_2)</td>
<td>10.9</td>
</tr>
<tr>
<td>11</td>
<td>Phosphoric acid, H(_3)PO(_4)</td>
<td>10.5</td>
</tr>
<tr>
<td>12</td>
<td>Sodium carbonate, Na(_2)CO(_3)</td>
<td>10.3</td>
</tr>
<tr>
<td>13</td>
<td>Sodium hydroxide, Na(_2)OH</td>
<td>9.7</td>
</tr>
<tr>
<td>14</td>
<td>Dichloroethane, H(_2)C═CH(_2)</td>
<td>9.4</td>
</tr>
<tr>
<td>15</td>
<td>Sulfur, S(_8)</td>
<td>9.2</td>
</tr>
<tr>
<td>16</td>
<td>Nitric acid, HNO(_3)</td>
<td>7.1</td>
</tr>
<tr>
<td>17</td>
<td>neoniterum trunco, [Ne(_3)NO(_3)]</td>
<td>6.6</td>
</tr>
<tr>
<td>18</td>
<td>Benzene, C(_6)H(_6)</td>
<td>6.4</td>
</tr>
<tr>
<td>19</td>
<td>Urea, [NN(_2)C==C==O]</td>
<td>6.4</td>
</tr>
<tr>
<td>20</td>
<td>Ethylene, C(_2)H(_4)</td>
<td>4.7</td>
</tr>
</tbody>
</table>
8. Chemistry of the Main Group Elements

TABLE 8-1
Top 20 Industrial Chemicals Produced in the United States, 2001

<table>
<thead>
<tr>
<th>Rank</th>
<th>Chemical</th>
<th>Production ($\times 10^9$ kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sodium chloride, NaCl</td>
<td>45.1</td>
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<tr>
<td>2</td>
<td>Sulfuric acid, H$_2$SO$_4$</td>
<td>36.3</td>
</tr>
<tr>
<td>3</td>
<td>Phosphoric acid, H$_3$PO$_4$</td>
<td>34.2</td>
</tr>
<tr>
<td>4</td>
<td>Nitrogen, N$_2$</td>
<td>29.1</td>
</tr>
<tr>
<td>5</td>
<td>Ethylene, H$_2$C=CH$_2$</td>
<td>22.5</td>
</tr>
<tr>
<td>6</td>
<td>Oxygen, O$_2$</td>
<td>21.8</td>
</tr>
<tr>
<td>7</td>
<td>Little, C$_6$H$_6$</td>
<td>18.1</td>
</tr>
<tr>
<td>8</td>
<td>Propylene, H$_2$C=CHCH$_3$</td>
<td>15.2</td>
</tr>
<tr>
<td>9</td>
<td>Ammonia, NH$_3$</td>
<td>11.1</td>
</tr>
<tr>
<td>10</td>
<td>Chlorine, Cl$_2$</td>
<td>10.9</td>
</tr>
<tr>
<td>11</td>
<td>Phosphoric acid, H$_3$PO$_4$</td>
<td>10.5</td>
</tr>
<tr>
<td>12</td>
<td>Sodium carbonate, Na$_2$CO$_3$</td>
<td>10.3</td>
</tr>
<tr>
<td>13</td>
<td>Sodium hydroxide, NaOH</td>
<td>9.7</td>
</tr>
<tr>
<td>14</td>
<td>Dichloroethane, H$_2$CICCH$_2$</td>
<td>9.4</td>
</tr>
<tr>
<td>15</td>
<td>Sulfur, S$_8$</td>
<td>9.2</td>
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<tr>
<td>16</td>
<td>Nitric acid, HNO$_3$</td>
<td>7.1</td>
</tr>
<tr>
<td>17</td>
<td>Ammonium nitrate, NH$_4$NO$_3$</td>
<td>6.8</td>
</tr>
<tr>
<td>18</td>
<td>Retene, C$_6$H$_3$</td>
<td>6.4</td>
</tr>
<tr>
<td>19</td>
<td>Urea, (NH$_2$)$_2$CO</td>
<td>6.4</td>
</tr>
<tr>
<td>20</td>
<td>Ethylbenzene, C$_6$H$_5$CH$_2$CH$_3$</td>
<td>4.7</td>
</tr>
</tbody>
</table>

---

more on that later...
8. Chemistry of the Main Group Elements

General Trends in Main Group Chemistry

Electrical Resistivities:

far right: non-metals
pnictogens (pnico = choke),
chalcogens, halogens & noble gases

middle:
C: Diamond, graphite & fullerenes
Si: Silicon, Ge: Germanium, Sn & Pb

far left: metals
alkali metals & alkaline earths:
luster, high ability to conduct heat & electricity, malleability

8. Chemistry of the Main Group Elements

General Trends in Main Group Chemistry

Electrical Resistivities: Carbon

<table>
<thead>
<tr>
<th>Conductivity parallel to layers, ( \sigma )</th>
<th>2.6 \times 10^4 ( \Omega^{-1}\text{cm}^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T ), ( \sigma )</td>
<td>metal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conductivity perpendicular to layers, ( \sigma )</th>
<th>( \sim 2 \Omega^{-1}\text{cm}^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T ), ( \sigma )</td>
<td>semiconductor</td>
</tr>
</tbody>
</table>

142 pm

C-C 154 pm

C=C 134 pm

154.5 pm
8. Chemistry of the Main Group Elements

General Trends in Main Group Chemistry

Electronegativities & Ionization Energies

Bond-Energy $X_2$
Acid-Strength $HX$
C Multiple-Bonding
H-Bonding

8. Chemistry of the Main Group Elements

Oxidation - Reductions Reactions

acids

basic

$\Delta G^0 = -nF\phi$

Frost-Diagram

Latimer-Diagram

$2H^+ + 2e^- \rightarrow H_2$
$\phi^0 = 0V$

$H_2 + 2e^- \rightarrow 2H$
$\phi^0 = -2.25V$

$H_2O + e^- \rightarrow OH^- + \frac{1}{2} H_2$
$\phi^0 = -0.828V$

$H_2 + 2e^- \rightarrow 2H$
$\phi^0 = -2.25V$

$H^+ \rightarrow H_2 \rightarrow 2.25 \rightarrow H$

$H_2O \rightarrow 0.828 \rightarrow H_2 \rightarrow 2.25 \rightarrow H$
8. Chemistry of the Main Group Elements

Oxidation - Reductions Reactions

Latimer-Diagram

acidic

\[ \begin{align*}
0 & \quad \text{O}_2 \quad 0.695 \\
-1 & \quad \text{H}_2\text{O}_2 \quad 1.763 \\
-2 & \quad \text{H}_2\text{O} \quad 0.065
\end{align*} \]

basic

\[ \begin{align*}
0 & \quad \text{O}_2 \quad 0.065 \\
-1 & \quad \text{H}_2\text{O}_2 \quad 0.867 \\
-2 & \quad \text{H}_2\text{O} \quad 0.065
\end{align*} \]

8. Chemistry of the Main Group Elements

Hydrogen - Occurrence

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Mass</th>
<th>Abundance</th>
<th>Stability</th>
<th>Decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protium ( ^1\text{H} )</td>
<td>1.007825</td>
<td>99.9855%</td>
<td>stable</td>
<td></td>
</tr>
<tr>
<td>Deuterium ( ^2\text{H} )</td>
<td>2.014102</td>
<td>0.0145%</td>
<td>stable</td>
<td></td>
</tr>
<tr>
<td>Tritium ( ^3\text{H} )</td>
<td>3.016049</td>
<td>10^{-15}%</td>
<td>stable</td>
<td>( \beta )-decay: ( ^3\text{He} \rightarrow ^3\text{H} + 0 ) electrons, ( \tau_{\beta} = 12.34 \text{ yrs} )</td>
</tr>
</tbody>
</table>

\( ^3\text{Li} + ^1\text{H} \rightarrow ^4\text{He} + ^3\text{H} \)
Hydrogen - Physical Properties

TABLE 8-2
Properties of Hydrogen, Deuterium, and Tritium

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Abundance (%)</th>
<th>Atomic Mass</th>
<th>Melting Point (K)</th>
<th>Boiling Point (K)</th>
<th>Critical Temperature (K)</th>
<th>Entalpy of Dissociation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protium (H, H)</td>
<td>99.985</td>
<td>1.007825</td>
<td>13.957</td>
<td>20.30</td>
<td>33.19</td>
<td>435.88</td>
</tr>
<tr>
<td>Deuterium (D, D)</td>
<td>0.015</td>
<td>2.014102</td>
<td>18.33</td>
<td>23.67</td>
<td>38.15</td>
<td>443.35</td>
</tr>
<tr>
<td>Tritium (H, T)</td>
<td>1.00 × 10⁻¹⁶</td>
<td>3.006699</td>
<td>20.62</td>
<td>25.04</td>
<td>40.6 (calc)</td>
<td>448.9</td>
</tr>
</tbody>
</table>

Properties

- Molecular weight: \( H_2O \) 18.0150, \( D_2O \) 20.0276, \( T_2O \) 22.0315
- Density at 25°C g/cm³: \( H_2O \) 0.99701, \( D_2O \) 1.1044, \( T_2O \) 1.2138
- Max. density of liquid water: \( H_2O \) 1.0000, \( D_2O \) 1.1059, \( T_2O \) 1.2150
- \( T \) @ max. density in °C: \( H_2O \) 3.98, \( D_2O \) 11.23, \( T_2O \) 13.4
- Melting point in °C: \( H_2O \) 0.00, \( D_2O \) 3.82, \( T_2O \) 4.49
- Boiling point in °C: \( H_2O \) 100.00, \( D_2O \) 101.42, \( T_2O \) 101.51

Hydrogen - Chemical Properties

The hydride anion \( H^- \) is a strong reducing agent \( (\bar{E}_0 = -2.25 \text{ V}) \) and a good ligand:

- \((BH_4^-)_3Al^{2+}\)
- \([\text{en}]_2Li^+\)AlH_4^-
- \((\text{Ph}_3P)\)ReH_8
8. Chemistry of the Main Group Elements

**Ionic (salt-like) Hydrides:** NaH, CsH, MgH₂

ΔE.N.: 1.3 (CsH) – 1.0 (MgH₂)  
only 30 - 18% ionic character  
ionic radius (exp.: 1.39 - 1.14, calc.: 2.04 Å)

**Metallic (interstitial) Hydride:** PdH₂, UH₃  
electr. conductance: M–M and M–H  
"metallic bonding"

hydridic H: UH₃ + 3H⁺ → U³⁺ + 3H₂  
protic H: cathod. H₂-evolution from electrolysis of PdH₂

**Covalent (molecular) Hydride:** B₂H₆, CH₄, NH₃  
molecular structures: Gillespie & Nyholm  
formation of polymers, dimers, oligomers & complex structures

---

[8. Chemistry of the Main Group Elements]

- Ammonia-(Haber-Bosch) Synthesis:  
  \[ \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \ (\alpha-\text{Fe Cat.}, 500\ ^\circ\text{C}, 400\ \text{bar}) \]

- Methanol Synthesis:  
  \[ \text{CO} + 2\text{H}_2 \rightarrow \text{CH}_3\text{OH} \ (\text{Cu/ZnO/Al}_2\text{O}_3 - \text{Cat.}, 200\ ^\circ\text{C}, \text{p}) \]

- Hydrogenation:  
  \[ \text{R}_2\text{C} = \text{CR}_2 + \text{H}_2 \rightarrow \text{R}_2\text{HC} - \text{CHR}_2 \ (\text{Cat.: Ni, Pd, Pt etc}) \]

Reduction agent:  
\[ \text{MO}_x + \text{H}_2 \rightarrow \text{M} + x\text{H}_2\text{O} \ (\text{high Temp.}) \]

- Rocket Fuel and Energy:  
  \[ \text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{Energy} \]
8. Chemistry of the Main Group Elements

The Alkaline-Metals - The Elements

Lithium (Li) Sodium (Na) Potassium (K)
Rubidium (Rb) Caesium (Cs) Francium (Fr)

http://www.chemsoc.org/viselements/pages/pertable_fl.htm

8. Chemistry of the Main Group Elements

The Alkaline-Metals - Physical Properties

TABLE 8.3
Properties of the Group 1(IA) Elements: The Alkali Metals

<table>
<thead>
<tr>
<th>Element</th>
<th>Ionization Energy (kJ mol⁻¹)</th>
<th>Electron Affinity (kJ mol⁻¹)</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
<th>Electronegativity</th>
<th>(\phi^\circ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li</td>
<td>520</td>
<td>60</td>
<td>180.5</td>
<td>1347</td>
<td>0.912</td>
<td>−3.04</td>
</tr>
<tr>
<td>Na</td>
<td>496</td>
<td>53</td>
<td>97.8</td>
<td>881</td>
<td>0.869</td>
<td>−2.71</td>
</tr>
<tr>
<td>K</td>
<td>419</td>
<td>48</td>
<td>63.2</td>
<td>766</td>
<td>0.734</td>
<td>−2.92</td>
</tr>
<tr>
<td>Rb</td>
<td>403</td>
<td>47</td>
<td>39.0</td>
<td>688</td>
<td>0.706</td>
<td>−2.92</td>
</tr>
<tr>
<td>Cs</td>
<td>376</td>
<td>46</td>
<td>28.5</td>
<td>705</td>
<td>0.659</td>
<td>−2.92</td>
</tr>
<tr>
<td>Fr</td>
<td>400</td>
<td>60</td>
<td>27</td>
<td>705</td>
<td>0.7</td>
<td>−2.93</td>
</tr>
</tbody>
</table>
The Alkaline-Metals – Chemical Properties

2 \( M \) + 2\( H_2O \) → 2\( MOH \) + \( H_2 \)

\( M \) + \( O_2 \) → \( M_2O, M_2O_2, MO_2 \)

\( M \) + \( xNH_3 \) → \( M^+ + e(NH_3)_x \)

\( RC=CH + e^- \rightarrow RC=C^- + \frac{1}{2} H_2 \)

\( S_8 + 2e^- \rightarrow S_8^{2-} \)
8. Chemistry of the Main Group Elements

The Alkaline-Metals - Chemical Properties

\[(15\text{crown}5)\text{Rb}^+\text{Na}^-\] inverse Na hydride

\[(15\text{crown}5)\text{Cs}^+\text{e}^-\] an “electride”


Bis(15crown5)cesium electride, space fill (left) and stick-model (right) with cell axis - Where is the electron?

3.7 – 4.8 Å large cationic complexes 8 – 10 Å

Electron Trapping Cavity

8. Chemistry of the Main Group Elements

The Alkaline-Metals - Chemical Properties

- Electrons can also be trapped in solid matrices (lattices) of simple salts (color-center or F-center, German: Farbe)

- Irradiation of salts with X-rays or ionizing radiation produces colored defects. The color of the defect depends on the nature of the host lattice (dimensions)

http://mrsec.wisc.edu/Edetc/cineplex/Fcenter/text.html

The Alkaline-Earths - The Elements

Beryllium (Be) Magnesium (Mg) Calcium (Ca)

Strontium (Sr) Barium (Ba) Radium (Ra)

http://www.chemsoc.org/viselements/pages/portable fla.htm
8. Chemistry of the Main Group Elements

The Alkaline-Earths - Physical Properties

<table>
<thead>
<tr>
<th>Element</th>
<th>Ionization Energy (kJ mol⁻¹)</th>
<th>Electron Affinity (kJ mol⁻¹)</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
<th>Electronegativity (V)</th>
<th>( M^+ \rightarrow M ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li</td>
<td>520</td>
<td>60</td>
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<td>688</td>
<td>0.706</td>
<td>-2.92</td>
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<td>-2.92</td>
</tr>
<tr>
<td>Fr</td>
<td>400 b,c</td>
<td>60 b,d</td>
<td>27</td>
<td></td>
<td>0.7 b</td>
<td>-2.92</td>
</tr>
</tbody>
</table>

Elements in Group 2 have similar chemical properties; tendency to loose two electrons to achieve noble gas e⁻ conf.

Exception: Beryllium, covalent rather than ionic bonding:

\[
\text{Mg} + 2\text{H}^+ \rightarrow \text{Mg}^{2+} + \text{H}_2
\]

\[
\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + \text{H}_2
\]

Elements in Group 2 have similar chemical properties; tendency to loose two electrons to achieve noble gas e⁻ conf.

\[\text{Be} \quad \text{Cl} \quad \text{Be} \quad \text{Cl} \quad \text{Be} \quad \text{Cl} \quad \text{Be} \quad \text{Cl} \quad \text{Cl} \quad \text{Be} \quad \text{Cl} \quad \text{Be} \quad \text{Cl} \quad \text{Cl} \quad \text{Be} \quad \text{Cl} \quad \text{Vapor} \quad \text{Vapor (>900°C)}\]

2-electron-3-center bonding (as in B₂H₆, Al₂Cl₆...)}
8. Chemistry of the Main Group Elements

The Group 13 Elements

Boron (B)

non-metal

<table>
<thead>
<tr>
<th>Element</th>
<th>Ionization Energy (kJ mol⁻¹)</th>
<th>Electron Affinity (kJ mol⁻¹)</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
<th>Electro-negativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>801</td>
<td>27</td>
<td>2180</td>
<td>3650°</td>
<td>2.051</td>
</tr>
<tr>
<td>Al</td>
<td>578</td>
<td>43</td>
<td>660</td>
<td>2467</td>
<td>1.613</td>
</tr>
<tr>
<td>Ga</td>
<td>579</td>
<td>30°</td>
<td>29.8</td>
<td>2403</td>
<td>1.756</td>
</tr>
<tr>
<td>In</td>
<td>558</td>
<td>30°</td>
<td>157</td>
<td>2080</td>
<td>1.656</td>
</tr>
<tr>
<td>Tl</td>
<td>589</td>
<td>20°</td>
<td>304</td>
<td>1457</td>
<td>1.789</td>
</tr>
</tbody>
</table>

http://www.chemsoc.org/viselements/pages/pertable_flas.htm

Diborane (B₂H₆)

convenient laboratory synthesis:
@ RT
3Na(BH₄) + 4 Et₂O • BF₃
→ 2B₂H₆ + 3NaBF₄ + 4Et₂O

industrial synthesis:
@ 450K
2BF₃ + 6NaH → B₂H₆ + 6NaF

B₂H₆ (ΔH° = +36 kJ/mol)
air-moisture sensitive
explodes with O₂ (stable borates)
very toxic

controlled pyrolysis of B₂H₆ via reactive BH₃ intermediates & H₂ form.
Boranes: Wade’s Rules

\[ B_nH_{n+2}^- \]  \hspace{1cm} \text{closo} \\
\[ B_nH_{n+4} \]  \hspace{1cm} \text{nido} \\
\[ B_nH_{n+6} \]  \hspace{1cm} \text{arachno} \\
\[ B_nH_{n+8} \]  \hspace{1cm} \text{hypho}

controlled pyrolysis of \( B_2H_6 \) via reactive BH\(_3\) intermediates

\[ B_{12}H_{12}^2^- \]  \hspace{1cm} \text{closo}

\[ B_{11}H_{11}^2^- \]  \hspace{1cm} \text{nido}

\[ B_{10}H_{10}^2^- \]  \hspace{1cm} \text{arachno}

\[ B_9H_9^2^- \]  \hspace{1cm} \text{hypho}

\[ B_8H_8^2^- \]  \hspace{1cm} \text{by the way… Al does it as well}
8. Chemistry of the Main Group Elements

Boron-Neutron Capture therapy (BNCT)

selective cell-killing with slow neutrons

no hit — no harm

ionizing α-particles travel one cell-diameter, very destructive
8. Chemistry of the Main Group Elements

Bonding in Diborane (B₂H₆)

Reductive representation for a molecule involving a boron atom:

\[ \text{H} \quad \text{B} \quad \text{H} \]

Reductive representation for a molecule involving a hydrogen atom:

\[ \text{H} \quad \text{H} \]

8. Chemistry of the Main Group Elements

Bonding in Diborane (B₂H₆)
Bonding in Diborane ($\text{B}_2\text{H}_6$)

...similar to

in higher borane clusters

B B

H H

don't forget about

(lowest energy)
8. Chemistry of the Main Group Elements

The Group 14 Elements

Carbon (C) 14

Non-metal

The Group 15 Elements

Nitrogen (N) 15

Non-metal

http://www.chemsoc.org/viselements/pages/portable fla.htm
8. Chemistry of the Main Group Elements

The Group 16 Elements

Oxygen (O)

8

The Group 17 Elements

Fluorine (F)

9
8. Chemistry of the Main Group Elements

### The Group 18 Elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Discoveried</th>
<th>Origin</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium (He)</td>
<td>A colorless, odorless gas that is totally unreactive. It is extracted from natural gas wells, some of which contain gas that is 7% helium. It is used in deep sea diving for balloons and, as liquid helium, for low temperature research. The Earth's atmosphere contains 5 parts per million by volume, totaling 400 million tons, but it is not worth extracting it from this source at present.</td>
<td>by Sir William Ramsay in London, and independently by P.T. Cleve and N.A. Langlet in Uppsala, Sweden in 1895</td>
<td>Greek 'neos' (new)</td>
<td>Deep sea diving, research</td>
</tr>
<tr>
<td>Neon</td>
<td>A colorless, odorless gas that comprises 18 parts per million of air. Neon will not react with any other substance. It is produced from liquid air for ornamental lighting (i.e. neon signs) because it glows red when an electrical discharge is passed through it.</td>
<td>1899 by Lord Rayleigh and Sir William Ramsay</td>
<td>Greek 'argos' meaning inactive</td>
<td>Ornamental lighting</td>
</tr>
<tr>
<td>Argon</td>
<td>The third most abundant gas, making up one percent of the atmosphere. The quantity has increased since the Earth was formed because radioactive potassium turns into argon as it decays. Argon is a colorless, odorless gas that is totally inert to other substances, and for this reason it is ideal in light bulbs.</td>
<td>by Sir William Ramsay and M.W. Travers in 1898</td>
<td>Greek 'kryptos', meaning hidden</td>
<td>Light bulbs</td>
</tr>
<tr>
<td>Krypton</td>
<td>A colorless, odorless gas that is inert to everything but fluorine gas. The isotope krypton 86 has a line in its atomic spectrum that is now the standard measure of length: 1 meter is defined as exactly 1,650,763.73 wavelengths of this line. Krypton is one of the rarest gases in the Earth's atmosphere, accounting for only 1 part per million by volume.</td>
<td>by Sir William Ramsay and M.W. Travers in 1898</td>
<td>Greek 'xenos', meaning strange</td>
<td>Scientific research</td>
</tr>
<tr>
<td>Xenon</td>
<td>A colorless, odorless gas that makes up 0.086 parts per million of the atmosphere. About half a ton a year is produced from liquid air and used for research purposes.</td>
<td></td>
<td>Greek 'xenos', meaning strange</td>
<td>Scientific research</td>
</tr>
</tbody>
</table>