Happy Spring!

Spring Begins: 3/20/17  5:29 AM CDT
<table>
<thead>
<tr>
<th>March 2017</th>
<th>Sunrise</th>
<th>Sunset</th>
<th>Length of Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>date</td>
<td>day</td>
<td></td>
<td></td>
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<tr>
<td>16 W</td>
<td>Sun</td>
<td>7:11</td>
<td>7:10</td>
</tr>
<tr>
<td>17 F</td>
<td>7:09</td>
<td>7:11</td>
<td>12 h 2m</td>
</tr>
<tr>
<td>18 Sat</td>
<td>7:07</td>
<td>7:12</td>
<td>12 h 5 m</td>
</tr>
<tr>
<td>19 Sun</td>
<td>7:06</td>
<td>7:13</td>
<td>12 h 7 m</td>
</tr>
<tr>
<td>20 M</td>
<td>7:04</td>
<td>7:14</td>
<td>12 h 10 m</td>
</tr>
<tr>
<td>21 Tu</td>
<td>7:03</td>
<td>7:15</td>
<td>12 h 12 m</td>
</tr>
<tr>
<td>22 W</td>
<td>7:01</td>
<td>7:15</td>
<td>12 h 14 m</td>
</tr>
<tr>
<td>23 Th</td>
<td>7:00</td>
<td>7:16</td>
<td>12 h 16 m</td>
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</table>

Spring Begins: 3/20/17 5:29 AM CDT
<table>
<thead>
<tr>
<th>March 2017</th>
<th>Sunrise</th>
<th>Sunset</th>
<th>Length of Day</th>
<th>Declination deg min</th>
</tr>
</thead>
<tbody>
<tr>
<td>date day</td>
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<td>22 W</td>
<td>7:01</td>
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<td>12 h 14 m</td>
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<tr>
<td>23 Th</td>
<td>7:00</td>
<td>7:16</td>
<td>12 h 16 m</td>
<td>+1 0.7</td>
</tr>
</tbody>
</table>

Spring Begins: 3/20/17  5:29 AM CDT
METALLIC ELEMENTS

2/3 of elements
30 commonly used
Lhs of periodic table
Separated from Nonmetals by
the Semimetals B, Si, Ge, As, Te
Mostly mined as nonmetallic ores
(exception: some noble metals)
# Periodic Chart of the Elements

## Group 1A (IA)
- **Hydrogen** (H)

## Group 2A (IIA)
- **Lithium** (Li)
- **Beryllium** (Be)

## Group 3A (IIIA)
- **Sodium** (Na)
- **Magnesium** (Mg)

## Group 4A (IVA)
- **Scandium** (Sc)
- **Titanium** (Ti)
- **Vanadium** (V)
- **Chromium** (Cr)
- **Manganese** (Mn)
- **Iron** (Fe)
- **Cobalt** (Co)
- **Nickel** (Ni)
- **Copper** (Cu)
- **Zinc** (Zn)

## Group 5A (VA)
- **Nitrogen** (N)
- **Oxygen** (O)
- **Fluorine** (F)

## Group 6A (VIA)
- **Sulfur** (S)
- **Chlorine** (Cl)
- **Bromine** (Br)
- **Krypton** (Kr)

## Group 7A (VIIA)
- **Iodine** (I)
- **Astatine** (At)

## Group 8A (VIII) (Noble Gases)
- **Neon** (Ne)
- **Argon** (Ar)

## Key Elements
- **Francium** (Fr)
- **Radium** (Ra)
- **Actinium** (Ac)
- **Lutecium** (Lu)

* The International Union for Pure and Applied Chemistry has not adopted official names or symbols for these elements.

---

**Lanthanide Series**
- **Ce**
- **Pr**
- **Nd**
- **Pm**
- **Sm**
- **Eu**
- **Gd**
- **Tb**
- **Dy**
- **Ho**
- **Er**
- **Tm**
- **Yb**

**Actinide Series**
- **Th**
- **Pa**
- **U**
- **Np**
- **Pu**
- **Am**
- **Cm**
- **Bk**
- **Cf**
- **Es**
- **Fm**
- **Md**
- **No**

---

*Copyright 1977, Fisher Scientific Company
Cat. No. S45520
## Periodic Chart of the Elements

### ABUNDANT METALS

<table>
<thead>
<tr>
<th>IA</th>
<th>Periodic Table</th>
<th>Noble Gases</th>
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<tbody>
<tr>
<td>1</td>
<td>Hydrogen</td>
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<tr>
<td>2</td>
<td>Lithium</td>
<td>Beryllium</td>
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<tr>
<td>3</td>
<td>Sodium</td>
<td>Magnesium</td>
</tr>
<tr>
<td>4</td>
<td>Potassium</td>
<td>Calcium</td>
</tr>
<tr>
<td>5</td>
<td>Rubidium</td>
<td>Strontium</td>
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<tr>
<td>6</td>
<td>Cesium</td>
<td>Barium</td>
</tr>
<tr>
<td>7</td>
<td>Francium</td>
<td>Radium</td>
</tr>
</tbody>
</table>

### Elements Noted

- **Lanthanide Series**:
  - 58 Ce
  - 59 Pr
  - 60 Nd
  - 61 Pm
  - 62 Sm
  - 63 Eu
  - 64 Gd
  - 65 Tb
  - 66 Dy
  - 67 Ho
  - 68 Er
  - 69 Tm
  - 70 Yb
  - 71 Lu

- **Actinide Series**:
  - 90 Th
  - 91 Pa
  - 92 U
  - 93 Np
  - 94 Pu
  - 95 Am
  - 96 Cm
  - 97 Bk
  - 98 Cf
  - 99 Es
  - 100 Fm
  - 101 Md
  - 102 No
  - 103 Lr

---

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Cat. No. S45520
### ABUNDANT METALS

> 0.1 wt. % of Earth's crust

- **Most Important**: Fe
- **Low density**: Si, Mg, Al, Ti
- **Other**: Mn

### SCARCE METALS

- **Base Metals**: Cu, Pb, Zn, Sn, Hg, Cd
- **Precious Metals**: Au, Ag, PGE's
- **Ferroalloy Metals**: Ni, Cr, Co, Mo, W, V
- **Special Metals**: Be, Bi, Cs, Ga, Ge, Zr, Li, REE....
IRON  $z=26$

Most important metal by far

5.6 % of Earth's crust

95% of metal consumed; 1 ton Fe & steel in avg. car

Many metals principally used as alloying constituents in steel

World iron & steel production $\sim 1.5$ billion metric tons

USA annual per capita consumption: $\sim 600$ kg

World Annual Ore Production = 1.0 billion metric tons

85% open pit

ore $\sim 30\%$ Fe; difference = scrap?

90% of cars ($10^7$ !) now recycled in USA

World Reserves = $150 \times 10^9$ metric tons

150 year supply

USSR (36%)  Australia  Brazil  Canada  USA
WORLD STEEL & ALUMINUM PRODUCTION

Steel MTons

Aluminum MTons

Craig et al 2001
World Steel Production

data source: World Steel Assn.
Main iron ore minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
<th>Iron Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematite</td>
<td>Fe₂O₃</td>
<td>69.9%</td>
</tr>
<tr>
<td>Magnetite</td>
<td>Fe₃O₄</td>
<td>72.4%</td>
</tr>
<tr>
<td>Goethite</td>
<td>FeOOH</td>
<td>62.9%</td>
</tr>
<tr>
<td>Siderite</td>
<td>FeCO₃</td>
<td>48.2%</td>
</tr>
<tr>
<td>Pyrite</td>
<td>FeS₂</td>
<td>46.6%</td>
</tr>
</tbody>
</table>

Two Oxidation States

- Ferrous iron (Fe⁺²)
  - Soluble
  - Stable in reducing, acid environments

- Ferric iron (Fe⁺³)
  - Insoluble
  - Stable in oxidizing environment
ECONOMIC FACTORS

1. Location/ Environmental impact/ Transportation
2. Tonnage
3. Grade
4. Stripping ratio
5. Amenability to benefication
6. Impurities
   esp P & S cannot be removed in blast furnaces
DEPOSIT TYPES

Igneous

Residual

Sedimentary
  Bog Iron
  Ironstones
  BIF’s
Igneous Deposits

Layered Mafic Intrusions (e.g., Bushveld, South Africa) -
  pure layers of chromite (Mg, Fe)Cr₂O₄ and vanadiferous magnetite (Fe₃O₄)

Skarns = Wallrock replacements @ igneous contacts:
  Cornwall PA
  Iron Springs, UT

Algoma Type- deposits of ancient, submarine hot springs (Canadian Shield)

MO Ores:
  Ozark dome (PreC)
    MO (1943) 1st state magnetic map (1:500:000) (WWII submarines)
  Bourbon high: drilled in 1943- at 1500’, hit 125’ of 44% Fe
  Iron Mtn: hematite veins in porphyry
  Pilot Knob: tabular hematite body // to volcanics.
  Pea Ridge (1953)
    Aeromagnetic anomaly
    1300’ – 3300’ deep- only underground Fe mine in USA
    tabular mass of mgt-hem in rhyolite volcanics
    600’ thick, 1/2 mile long
CHROMITE LAYERS, BUSHVELD COMPLEX

FeCr$_2$O$_4$  2.05 GA

Kesler 1994
Iron Springs District, Utah

Park & MacDiarmid, 1975
Igneous Deposits

Layered Mafic Intrusions (e.g., Bushveld, South Africa) -
pure layers of chromite \((\text{Mg, Fe})\text{Cr}_2\text{O}_4\) and vanadiferous magnetite \((\text{Fe}_3\text{O}_4)\)

Skarns = Wallrock replacements at igneous contacts:
Cornwall PA
Iron Springs, UT

Algoma Type- deposits of submarine hot springs (Canadian Shield)

MO Ores:
Ozark dome (PreC)
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\textit{Aeromagnetic anomaly}
1300’ – 3300’ deep- only underground Fe mine in USA
Tabular mass of mgt-hem in rhyolite volcanics; also REE’s:
600’ thick, 1/2 mile long
Magnetic Anomaly Map

Zietz et al. 1984
Magnetic Anomaly Map

Zietz et al., 1984
Residual Deposits: Weathering environments- esp. tropical laterites

Ferruginous Laterites:
  Hard red residual soils, to 30% Fe as Fe(OH)₃
  Huge resource but mining would cause environmental problems

Missouri Ores: Filled sinks (good drainage, leaching)
  Pyrite (sulfuric acid WWII)
  Maramec Spring
    Hematite (Fe₂O₃; both red and specular) & Goethite (FeOOH)
    Pyrite parent?
    to 200’ deep, 5 acres
  Gasconade Dolostone-Roubidoux Sandstone
LATERITES

Craig et al 2001
NE of Perth, Australia
THE MARAMEC ORE BANK

The Maramec Ore Bank is one of those referred to as ‘filled sinks’ and is cited as being a good example of ‘elongated inverted cone type’. In other words, it widens out as it goes down. The main workings of the mine consisted of a circular pit 225 ft in diameter and about 80 ft deep. The main ore body occurred 10 to 30 ft below the surface of the ground. The position of the ore made mining a simple process. The overlying soil and debris were stripped from the mine with pick and shovel and was dumped to one side out of the way. Then, using pick, chisels, hand drills, and black powder, the miners broke the ore into chunks small enough to be hauled to the surface in wagons pulled by mule teams. The ore from the mine that could be profitably mined was in three varieties, (1) a purple, pink, ore, (2) a soft red ore and (3) a hard specular ore. Also, the ‘albers’ or mounds of clay that is located in the center of the pit is the residue material left from the weathering of the dolomite.

COLUMNS SECTION
Through Center of Pit

ORE BODY

REDOX MATERIAL

SANDSTONE

DOLOMITE

1.2-2.0 ft. water, sandy soil, with opencast ore
2.2-2.7 ft. Alternating layers of sandstone and massive chert.
2.0-2.3 ft. Jaspers and jasperoid banding, small amounts of clay banding,
2.1-2.5 ft. Broken sandstone and chart with iron.
2.2-2.5 ft. Gold Chart.
2.0-2.2 ft. White clay with broken clay.
1.7-2.0 ft. Red clay with layers of green clay.
2.0-2.5 ft. Green clay with traces of iron carbonate; soft,
1.0-2.0 ft. Yellow clay with dark ‘pencil’ ore.
1.0-2.0 ft. Chart breaking in clay banding.
1.0-2.0 ft. Red, sandy clay with chart fragments.
1.0-2.0 ft. Shredded sandstone.
1.0-2.0 ft. Shredded dolomite.

Maramec Iron Mine, MO

Criss
Sedimentary Deposits

Bog Iron Deposits:
Small, variable grade deposits in modern swamps, bogs & lakes
Formed under reducing conditions, esp. acidic, organic-rich environments
Used historically, but no longer important

Ironstones: Large, massive sedimentary beds, mostly shallow, near-shore
Proterozoic (ca. 1.8 Ga) to Pliocene; mostly Lower Paleozoic & Jurassic
Goethite; also hematite, siderite or chamosite (7A clay)

Minette Type (Jurassic)- Europe (e.g. Alsace-Lorraine)
Commonly oolitic;
Limonite, chamosite & siderite
30-35 % Fe in carbonate & silica gangue

Clinton Fm. (Silurian) NY to ALA (Birmingham District)
Massive, oolitic, hematite-chamosite-siderite beds, sometimes > 50 % Fe
Shallow marine (lots fossils; many replaced by hematite)
Plenty of clastic material Cross-bedding Mudcracks

cf. Lake Chad (large, shallow lake)
oolites occur in 6,000 km² area @ depths of 1-3 m
∼ 0.25 mm dia, montmorillonite nuclei coated w/ goethite & silica)
Banded Iron Formations “BIF's” Chemical sediments
Proterozoic (mostly \textbf{2.6-1.8 Ga}) but back to oldest rocks 3.8 Ga
All continents, but esp. USSR, Brazil, Australia
Huge deposits: 30-700 m thick, to 1000's km\(^2\)  20-40\% Fe
Most of the current iron supply, & most of the reserves
Chemical Precipitates: Thin-bedded Magnetite or Hematite & Chert (No goethite)
  Formed in broad sedimentary basins
  Facies: Fe-oxides near-shore \(\rightarrow\) Fe carbonates & Fe silicate \(\rightarrow\) distal Fe sulphides

\textbf{\textsim 1.8 Ga}  Rise of free oxygen in atmosphere (also ozone; CO\(_2\) decrease)
Procaryots (no nucleus; e.g. blue green algae; fission) \(\rightarrow\) Eucaryots (nucleus; mitosis)
O\(_2\) content progressively rose;
  by 0.7 Ga enough oxygen to support metazoans (Ediacaran fauna)
Witwatersrand (Au & U Placers; 2.3 – 2.8 AE), BIF's \(\rightarrow\) Ironstones, Metazoans

Historically, only mined limited zones enriched to 55\% Fe by supergene weathering
Steel pioneer Andrew Carnegie's 1908 statement -- look to future
Now can use taconites (banded ores)
\textbf{Benefication} (= concentration of ore minerals)
  Grind and form into uniform, \(\sim\) 65\% Fe, 1-2 cm pellets (clay binder)
  Easy to handle & transport,
  Good, uniform blast furnace charge
BIF, Negaunee Fm., MI
Hematite-chert bands

H.L. James
*Economic Geology*
Hull Rust Mine, MN
> 1 Gtons

240 ton
SMELTING
Reduction in Blast Furnace
Introduce charge in top, withdraw iron from bottom

Process

Charge = 1.6 tons pellets + 0.7 tons Coke + 0.2 tons Limestone + 4 tons air

=> 1600°C => 1 ton Fe

Process makes CO from coke, then uses CO to reduce Fe-oxides:

C (coke) + 1/2 O₂ (air => CO

3 CO + Fe₂O₃ (ore) => 2 Fe (pig iron) + 3 CO₂

Limestone combines w/ SiO₂ & Al₂O₃ in slag => aggregate, road metal
Buckeye Furnace, OH
built 1851
Sand House,
Buckeye Furnace

Ohio Historical Society
USA

  Dominant steel producer from ~1900 to 1970
  Currently produces only 5% of world total
  Steel importer

Historically, USA had:
  Requisite Raw Materials = Limestone, Coal & Fe ore
  Great Lakes for transport

Post WWII
  USA had intact industry
  USA had 47% of world steel production in 1950
  World Production underwent 6-fold increase
  Japan, Europe modernized industry & now are more efficient
  Currently, China dominates production (50%)
  Pittsburgh, Gary, Cleveland = "Rust Belt"

USA loss of market share = Problem is economic competitiveness
STEEL PRODUCTION

USA
Common Market
Japan
Soviet Union
Other
China

Craig et al 2001
# Iron Ore Production 2009

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>World Production, By Country (Thousand metric tons)</th>
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<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>880,000</td>
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<tr>
<td>2</td>
<td>Australia</td>
<td>394,000</td>
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<tr>
<td>3</td>
<td>Brazil</td>
<td>300,000</td>
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<td>4</td>
<td>India</td>
<td>245,000</td>
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<td>Russian Federation</td>
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<td>6</td>
<td>Ukraine</td>
<td>66,476</td>
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<tr>
<td>7</td>
<td>South Africa</td>
<td>55,313.05</td>
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<td>8</td>
<td>Iran, Islamic Republic Of</td>
<td>33,000</td>
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<td>9</td>
<td>Canada</td>
<td>31,700</td>
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<tr>
<td>10</td>
<td>United States</td>
<td>26,696</td>
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<td>Kazakhstan</td>
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<td>18</td>
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### Raw Steel Production 2007

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>World Production, By Country (Thousand metric tons)</th>
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<tbody>
<tr>
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<td>China</td>
<td>489,240</td>
</tr>
<tr>
<td>2</td>
<td>Japan</td>
<td>120,203</td>
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<td>3</td>
<td>United States</td>
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<td>Russian Federation</td>
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<td>India</td>
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<tr>
<td>25</td>
<td>Netherlands</td>
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</tr>
</tbody>
</table>

**2013**
- USA: 5.2%
- China: 50%

indexmundi