Carbon

Discovered: Known since ancient times. It was first recognized as an element in the second half of the 18th century.

Name: A.L. Lavoisier proposed *carbon* in 1789 from the Latin *carbo* meaning "charcoal." A.G. Werner and D.L.G. Harsten proposed *graphite* from the Greek *grafo* meaning "to write," referring to pencils, which were introduced in 1594. *Diamond* is a hybrid word from the Greek meaning "transparent" and "invincible." The blue color of the Hope diamond arises from a trace amount of boron substituting for carbon in the lattice. Likewise, trace nitrogen accounts for the yellow color of the Tiffany diamond. In 1985, a new allotrope of carbon *buckminsterfullerene* was created in the laboratory. It consists of 60 carbon atoms in an arrangement similar to surface of a soccer ball. Its name derives from the inventor of the geodesic dome whose name is very similar and it is found in interstellar space. Other enclosed structures with differing numbers of carbon atoms also exist.

Occurrence: Widespread, but not particularly plentiful in nature. Major sources: elemental forms, carbonates, CO_2, living and dead organic matter. (The first two are most important).

Isolation: Found naturally (both graphite and diamond); both can also be made artificially.

Cost for 1 gram, 1 mole: $0.10, $1.16 (graphite)

Natural Isotopes: ^{12}C (98.89%) ^{13}C (0.11%) ^{14}C (trace)

	Graphite	Diamond
Physical and Chemical Properties:	Very soft (Moh's < 1)	Very hard (Moh's = 10)
	Electrical conductor	Electrical insulator
	Black in color	Colorless
	Less dense form	More dense form
	More reactive form	Less reactive form
	Flaky texture	

Reactions: burning: $C + O_2 \xrightarrow{\Delta} CO_2$

$C + \frac{1}{2} O_2 \xrightarrow{\Delta} CO$

$H_2O_{(g)} + C_{(s)} \xrightarrow{\Delta} CO_{(g)} + H_{2\,(g)}$ ("water-gas shift" reaction)

Uses: *Graphite*: Solid lubricant
Electrodes
Crucibles
Neutron moderator in nuclear reactors
High strength composites
(in tires, rackets, skis, etc.)

Diamonds: Grinding/abrasives
Adornment

Chlorine

Discovered: By C.W. Scheele in 1774, but he thought it was a compound. Sir Humphrey Davy demonstrated that Cl_2 was an element in 1810.

Name: Proposed by Davy in 1811 it comes from the Greek *chloros* meaning "yellowish or light green" referring to its color.

The word *halogen* was introduced in 1811 by J.S.C. Schweigger to describe the property of chlorine to produce salts when directly reacted with metals. It comes from a hybrid of Greek words meaning "to produce sea salt."

Occurrence: Moderate to low abundance, widespread in nature, and never found free. Most chlorine is found in NaCl in either evaporated water pools or the ocean. $MgCl_2$ and $CaCl_2$ are also found in substantial quantities.

Isolation: a) Electrolysis of aqueous NaCl (to Cl_2, H_2, and NaOH)
b) Electrolysis of molten NaCl (to Cl_2 and Na)

Cost of 1 gram, 1 mole: 0.01, $0.35

Natural Isotopes: ^{35}Cl (75.5%) ^{37}Cl (24.5%)

Physical and Chemical Properties:
Yellow-green gas with a sharp odor
Strong oxidant
Very electronegative
Very reactive
Dissolves in and reacts with water
Toxic

Reactions:
$Cl_2 + H_2 \xrightarrow{\text{dark}}$ No reaction
$Cl_2 + H_2 \xrightarrow{h\square} 2\,HCl$
$Cl_2 + CO \longrightarrow Cl_2CO$ (phosgene, WW I poison gas)
$Cl_2 + H_2O \rightleftharpoons HCl + HClO$ (gives bleach when NaOH is present)
Cl_2 reacts with aqueous $CaCl_2$ at 0 ºC to form solid $Cl_2\bullet 7.3H_2O$
$Cl_2 + PhI \xrightarrow{\text{cold}} PhI\bullet Cl_2$ (a "solid form" of chlorine that is easily weighed)

Uses: Synthesis of chloro organic compounds
Paper bleaching
Disinfectants (e.g. of water supplies)
Synthesis of inorganic chlorides

Fluorine

Discovered: First isolated by H. Moissan in 1886 after 74 years of efforts by various investigators (The unknown element had been observed as a constituent of minerals.)

Name: From the mineral fluorospar (CaF_2), suggested in 1812 by A.-M. Ampere (almost 75 years before it was isolated!). Fluorospar is derived from the Latin word *fluor* meaning "to flow."
Note: Fluorescence was first observed as the light emission from fluorospar in 1852.

Occurrence: Moderately abundant, never occurs as the free element. Most common minerals: fluorite (CaF_2), cryolite (Na_3AlF_6), and fluorapatite ($Ca_5(PO_4)_3F$).

Isolation: Interestingly, the only practical method of preparing F_2 is the one used to isolate it the first time in 1886 (with safeguards to prevent the fire that happened then). Electrolysis of KF in anhydrous HF (1:2) at 72 ºC. H_2 is the by-product gas and must be kept separated from the F_2 to prevent explosions. The cells contain no flammable material and have a protective fluoride coating for the same reason.

Cost of 1 gram, 1 mole: $1.05, $19.90

Natural Isotopes: ^{19}F (100%)

Physical and Chemical Properties:

Most electronegative element
Pale yellow gas that condenses to a canary yellow liquid
Corrosive
F-F bond energy is low
Most reactive of the elements
Finely divided metals, glass, ceramics, carbon, and water(!) spontaneously burn in the presence of F_2
Low melting point
Binary fluorides are unusually volatile (compared with the corresponding halides or oxides)

Reactions:

$U + 3\,F_2 \longrightarrow UF_6$ (used to separate U isotopes for nuclear power, accounts for 70-80% of F_2 use)
$Cl_2 + 3\,F_2 \longrightarrow 2\,ClF_3$ (used as an incendiary by Germany in WWII)
F_2 + organic compounds $\longrightarrow$ explosion and fire

Uses: Artificial blood (fully fluorinated long hydrocarbons store large amounts of oxygen)
Etching glass (HF)
Hydrochlorofluorocarbons are used as refrigerants and as inert gases in the computer industry. Originally, chlorofluorocarbons were used for this purpose, but have been phased out of use because they damage the ozone layer. This is ironic as they were originally used because they were completely non-toxic and unreactive towards equipment.
Dental health. (Fluoride is added to most drinking water supplies and toothpastes. It replaces a surface -OH group on the enamel making it less susceptible to acid attack.)

Nitrogen

Discovered: Independently by Daniel Rutherford and by C.W. Scheele and H. Cavendish in 1772.

Name: Proposed by J.-A.-C. Chaptal in 1790 from the realization that it was a component of HNO_3 and nitrates (from the Greek *niter* and *gen* meaning "to form from salt peter") A.L. Lavoisier suggested *azote* (meaning "no life" referring to its inability to support aerobic life, c.f. azides, azo compounds, etc.). Likewise, the German term for nitrogen, *Stickstoff*, means "to choke."

Occurrence: N_2 is 75-78 volume %, mole %, and weight % of air. It is non-abundant in the crust, however KNO_3 and $NaNO_3$ deposits are found in some arid regions of the world.

Isolation: Liquification and distillation of air (b.p. -196 ºC, 77 K)

Cost of 1 gram, 1 mole: \$0.0014, \$0.04

Natural Isotopes: ^{14}N (99.6%) ^{15}N (0.4%)

Physical Properties: Odorless, colorless gas
Chemically inert
Very electronegative
Atomic N can be generated by passing an electrical discharge through a *ca.* 1 torr sample of N_2. (In spite of the very favorable thermodynamics of recombination, several minutes are required for complete reaction because at low pressure this is a termolecular process.)

Reactions:

$$N_2 + 3\,H_2 \underset{\text{high T}}{\overset{\text{high P}}{\rightleftharpoons}} 2\,NH_3 \qquad \text{(ammonia)}$$

$$4\,NH_3 + 8\,O_2 \xrightarrow{\Delta} 4\,HNO_3 + 4\,H_2O$$

$$NH_4NO_3 \xrightarrow{\Delta} 2\,H_2O + N_2O \quad \text{(laughing gas)}$$

$$C_3H_5(OH)_3 + 3\,HNO_3 \xrightarrow{\text{catalyst}} 3\,H_2O + C_3H_5(NO_3)_3 \text{ (nitroglycerine)}$$

Uses: NH_3 is the largest volume chemical produced in the U.S. (by moles) (It is the starting material for many N containing chemicals.)
Fertilizers (3 of the top 20 chemicals produced in the U.S. in 2020 contained N)
Explosives (1,3,5-trinitrotoluene, nitroglycerin, etc.)
Refrigerant (liquid N_2)
Anesthetic (laughing gas)
Comprises about 15% of proteins by weight

Oxygen

Discovered: J. Priestly and C.W. Scheele (independently) in 1773-74.

Name: By A.L. Lavoisier in 1777. It is a hybrid word derived from the Greek *oxys* meaning "acid former" from the belief that it was a constituent of all acids. "Ozone" is derived from the Greek word *ozein* meaning "to smell."

Occurrence: Comprises about 20% of our atmosphere, 45% of the earth's crust, and 89% of water. It is also by far and away the major component of bodies of water. There are 2 allotropes of oxygen: dioxygen (O_2) and ozone (O_3), both of which occur in nature. Almost all of the O_2 found in nature is of biological origin.

Isolation: Obtained by the fractional distillation of air. Ozone is formed by exposing dioxygen to an electric discharge or to ultraviolet light. One can often smell ozone near electrical equipment that produces sparks.

Cost of 1 gram, 1 mole: \$0.0024, \$0.08

Natural Isotopes: ^{16}O (99.8%) ^{17}O (0.04%) ^{18}O (0.2%)

Physical and Chemical Properties:	Dioxygen	**Ozone**
	Paramagnetic	Diamagnetic
	Colorless, odorless gas	Blue gas with a sharp odor
	Safe to breathe	Toxic ($[O_3] > 1$ ppm for time > 10 min)
	Very reactive (reacts with every element except He, Ne, and Ar)	Even more reactive
	Strong oxidizer	Very strong oxidizer
	Fairly soluble in water and organic solvents	Bent Structure
	Blue when liquefied	

Reactions: Dioxygen: $2\ HC{\equiv}CH + 5\ O_2 \xrightarrow{\Delta} 4\ CO_2 + 2\ H_2O$

$2\ H_2 + O_2 \xrightarrow{\Delta} 2\ H_2O$

Ozone: Ozone is an important component of the stratosphere where it absorbs harmful UV radiation before it reaches the ground. This ozone layer may be in danger because of the slow diffusion of chlorofluorocarbons (Freons®) into the stratosphere. The reactions that are thought to occur there are shown below.

$CF_3Cl \xrightarrow{h\nu} CF_3 + Cl$

$Cl + O_3 \longrightarrow ClO + O_2$ (*Note*: This and the next reaction form a

$ClO + O \longrightarrow Cl + O_2$ repeating chain.)

Uses: Blast furnaces in steel making (atmosphere enrichment)

Industrial NH_3, MeOH, and ethylene oxide syntheses

Rocket fuel (with H_2), used in the space shuttle

Phosphorus

Discovered: By Hanning Brandt in 1669 (by putrefying urine, boiling it to a paste, then reductively distilling it; think about this next you don't like a lab that's been assigned)

Name: From the Greek (*fos* and *fero*) meaning "light bearing" because it glows in the dark when exposed to air. Brandt was the first person credited with naming an element. All previous elements had been known since antiquity.

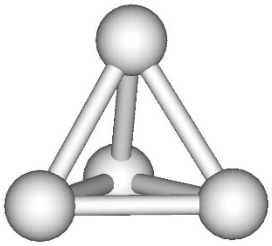
Occurrence: Moderate abundance, widespread distribution, but never found pure. There are over 200 P containing minerals, the apatites ($Ca_3(PO_4)_2 \bullet CaX_2$) being the most significant.

Isolation: $2\ Ca_3(PO_4)_2 + 6\ SiO_2 + 10\ C \longrightarrow P_4 + 6\ CaSiO_3 + 10\ CO$

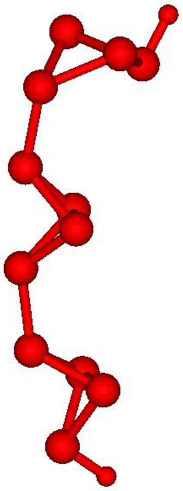
Cost of 1 gram, 1 mole: $0.25, $7.81 (red)

Natural Isotopes: ^{31}P (100%)

Physical and Chemical Properties: At least 5 crystalline forms plus several amorphous forms are known (all melt to the same liquid).



White P_4 - Most common form
Most reactive form
Crystalline
Waxy consistency
Slow oxidation of vapor emits yellow-green light (phosphorescence)
Burns in air
Highly toxic (fatal dose *ca.* 50 mg)



Red P_4 - Made by heating white P_4 to *ca.* 300 ºC
Less reactive than white
Essentially non-toxic
Polymeric

Black P_4 - Made by heating white P_4 under pressure
Thermodynamically most stable form
Semi-conductor
Highly branched polymer

Reactions:

$P_4 + O_2 \xrightarrow{\Delta} P_4O_6$ or P_4O_{10}
$P_4O_{10} + 6\ H_2O \longrightarrow 4\ H_3PO_4$
$P_4 + S \longrightarrow P_4S_3$ (matches that will strike anywhere)

Uses:
Fertilizers (as phosphates)
Fine china ($Ca_3(PO_4)_2$)
Detergents and water softeners (as phosphates)
Fireworks (phosphorus and its compounds)

Silicon

Discovered: J.J. Berzelius in 1824

Name: From the Latin *silex* for "flint." It ends in -on because of its resemblance to carbon. Prehistoric weapons and tools were made with this silicon containing mineral.

Occurrence: It is the second most abundant element in the earth's crust, but only the seventh most abundant in the universe. It never occurs free and is almost always combined with oxygen. It is a component of many minerals: olivine ($M^{II}_2SiO_4$), quartz (SiO_2), amethyst, flint, opal, agate, jasper, granite, asbestos, micas, feldspars, etc.

Isolation: $SiO_2 + 2\,C \xrightarrow{\Delta} Si + 2\,CO$

Cost for 1 gram, 1 mole: $0.48, $13.55

Natural Isotopes: ^{28}Si (92.2%) ^{29}Si (4.7%) ^{30}Si (3.1%)

Physical and Chemical Properties:

Semiconductor
Metalloid
Shiny blue-gray metallic luster
Low tendency towards catenation (doesn't form long chains with itself)
Multiple bonds are much weaker than for carbon analogues (because silicon doesn't use its p-orbitals for π-bonding)
Chemically inert (attacked by halogens, dilute alkali)
Very oxophilic

Reactions:

$Si + C \xrightarrow{2000\ ^{\circ}C} (SiC)_x$ (carborundum)

$Si + 2\,Cl_2 \xrightarrow{\text{red heat}} SiCl_4$

Uses:

Semi-conductors
Construction (SiO_2, sand in cement)
Recreation (SiO_2, sand on beach)
Glass (SiO_2)
Abrasives (SiC)
Synthetic oils, rubbers, and greases (silicones)

Sulfur

Discovered: By cavemen. First proposed as an element by A.L. Lavoisier in 1777.

Name: From the Latin word *sulphyrium*, which is derived from the Sanskrit *sulvere*, meaning "the enemy of copper." and is likely to be an alchemical term. It is called *brimstone* in the Bible, which is a corruption of the German word for sulfur *brennstein* meaning "stone that burns." It is a *chalcogen* which means "derived from copper (or bronze)" from the Greek.

Occurrence: Moderately abundant and widespread in nature, usually found in combined form. Minerals: sulfates [gypsum ($CaSO_4 \bullet 2H_2O$), barite ($BaSO_4$), epsom salts ($MgSO_4$)], sulfides [pyrite (FeS_2, cinnabar (HgS), galena (PbS), sphalerite (ZnS), chalcopyrite ($CuFeS_2$)]. Elemental sulfur. H_2S is found in natural gas. Large deposits of elemental sulfur are located along the Gulf Coast in Texas and Louisiana.

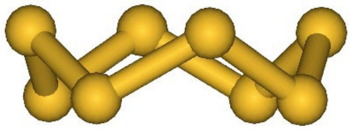
Isolation: Hot water and compressed air are forced in the caprock of salt domes melting the sulfur and forcing it out. (The sulfur is probably the result of anaerobic bacteria consuming sulfate deposits.) This sulfur is usually very pure (> 99%). Some sulfur is obtained as a result of contamination of natural gas (CH_4) by H_2S (up to 30%).

Cost for 1 gram, 1 mole: $0.05, $1.60

Natural Isotopes: ^{32}S (95.0%) ^{33}S (0.8%) ^{34}S (4.2%) ^{36}S (0.01%)

Physical and Chemical Properties:

Shows the greatest allotropy of any element
Has a strong tendency to catenate
Very reactive, particularly at higher temperatures
Combines directly with most elements
Most common allotrope is orthorhombic α-cyclo S_8
Good thermal and electrical insulator
Tasteless with little odor
Colors of some sulfur allotropes
$S_{2\,(g)}$ - blue-violet S_6 - orange-red
$S_{3\,(g)}$ - cherry red $S_{8\,(s)}$ - yellow



Reactions:

$S + O_2 \xrightarrow{\Delta} SO_2$ ("burning")
$2\,S + O_2 \xrightarrow{\Delta} 2\,SO_3$
$SO_3 + H_2O \longrightarrow H_2SO_4$ (a source of acid rain)

Uses: Fungicides and insecticides
Vulcanizing rubber
A component of black (gun)powder
Almost 90% of sulfur is converted into H_2SO_4 (40 million tons/year worldwide)
Most uses of sulfur make use of sulfuric acid as a starting material
Fertilizer (*ca.* 50% of the H_2SO_4)
Synthetic fabrics
Paper production