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**Phosphorus**

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This article is about the chemical element. For other uses, see [Phosphorus (disambiguation)](https://en.wikipedia.org/wiki/Phosphorus_(disambiguation)).

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| --- | --- |
| Phosphorus,  15P | |
| [PhosphComby.jpg](https://en.wikipedia.org/wiki/File:PhosphComby.jpg)  waxy white (yellow cut), red (granules centre left, chunk centre right), and violet phosphorus | |
| **General properties** | |
| **Pronunciation** | [/ˈfɒsfərəs/](https://en.wikipedia.org/wiki/Help:IPA/English) ​([*FOS-fər-əs*](https://en.wikipedia.org/wiki/Help:Pronunciation_respelling_key)) |
| **Appearance** | Colourless, waxy white, yellow, scarlet, red, violet, black |
| [**Standard atomic weight**](https://en.wikipedia.org/wiki/Standard_atomic_weight) **(*A*r, standard)** | 30.973761998(5)[[1]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-CIAAW2016-1) |
|  | |
| [**Abundance**](https://en.wikipedia.org/wiki/Abundance_of_the_chemical_elements) | |
| in the [Earth's crust](https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust) | 5.2 (taking silicon as 100) |
| **Phosphorus in the** [**periodic table**](https://en.wikipedia.org/wiki/Periodic_table) | |
| |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 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[Neon](https://en.wikipedia.org/wiki/Neon) | | [Sodium](https://en.wikipedia.org/wiki/Sodium) | [Magnesium](https://en.wikipedia.org/wiki/Magnesium) |  | | | | | | | | | | | | | | | | | | | | | | | | [Aluminium](https://en.wikipedia.org/wiki/Aluminium) | [Silicon](https://en.wikipedia.org/wiki/Silicon) | Phosphorus | [Sulfur](https://en.wikipedia.org/wiki/Sulfur) | [Chlorine](https://en.wikipedia.org/wiki/Chlorine) | [Argon](https://en.wikipedia.org/wiki/Argon) | | [Potassium](https://en.wikipedia.org/wiki/Potassium) | [Calcium](https://en.wikipedia.org/wiki/Calcium) | [Scandium](https://en.wikipedia.org/wiki/Scandium) |  | | | | | | | | | | | | | | [Titanium](https://en.wikipedia.org/wiki/Titanium) | [Vanadium](https://en.wikipedia.org/wiki/Vanadium) | [Chromium](https://en.wikipedia.org/wiki/Chromium) | [Manganese](https://en.wikipedia.org/wiki/Manganese) | [Iron](https://en.wikipedia.org/wiki/Iron) | [Cobalt](https://en.wikipedia.org/wiki/Cobalt) | [Nickel](https://en.wikipedia.org/wiki/Nickel) | [Copper](https://en.wikipedia.org/wiki/Copper) | [Zinc](https://en.wikipedia.org/wiki/Zinc) | [Gallium](https://en.wikipedia.org/wiki/Gallium) | [Germanium](https://en.wikipedia.org/wiki/Germanium) | [Arsenic](https://en.wikipedia.org/wiki/Arsenic) | [Selenium](https://en.wikipedia.org/wiki/Selenium) | [Bromine](https://en.wikipedia.org/wiki/Bromine) | [Krypton](https://en.wikipedia.org/wiki/Krypton) | | [Rubidium](https://en.wikipedia.org/wiki/Rubidium) | [Strontium](https://en.wikipedia.org/wiki/Strontium) | [Yttrium](https://en.wikipedia.org/wiki/Yttrium) |  |  | | | | | | | | | | | | | [Zirconium](https://en.wikipedia.org/wiki/Zirconium) | [Niobium](https://en.wikipedia.org/wiki/Niobium) | [Molybdenum](https://en.wikipedia.org/wiki/Molybdenum) | [Technetium](https://en.wikipedia.org/wiki/Technetium) | [Ruthenium](https://en.wikipedia.org/wiki/Ruthenium) | [Rhodium](https://en.wikipedia.org/wiki/Rhodium) | [Palladium](https://en.wikipedia.org/wiki/Palladium) | [Silver](https://en.wikipedia.org/wiki/Silver) | [Cadmium](https://en.wikipedia.org/wiki/Cadmium) | [Indium](https://en.wikipedia.org/wiki/Indium) | [Tin](https://en.wikipedia.org/wiki/Tin) | [Antimony](https://en.wikipedia.org/wiki/Antimony) | [Tellurium](https://en.wikipedia.org/wiki/Tellurium) | [Iodine](https://en.wikipedia.org/wiki/Iodine) | [Xenon](https://en.wikipedia.org/wiki/Xenon) | | [Caesium](https://en.wikipedia.org/wiki/Caesium) | [Barium](https://en.wikipedia.org/wiki/Barium) | [Lanthanum](https://en.wikipedia.org/wiki/Lanthanum) | [Cerium](https://en.wikipedia.org/wiki/Cerium) | [Praseodymium](https://en.wikipedia.org/wiki/Praseodymium) | [Neodymium](https://en.wikipedia.org/wiki/Neodymium) | [Promethium](https://en.wikipedia.org/wiki/Promethium) | [Samarium](https://en.wikipedia.org/wiki/Samarium) | [Europium](https://en.wikipedia.org/wiki/Europium) | [Gadolinium](https://en.wikipedia.org/wiki/Gadolinium) | [Terbium](https://en.wikipedia.org/wiki/Terbium) | [Dysprosium](https://en.wikipedia.org/wiki/Dysprosium) | [Holmium](https://en.wikipedia.org/wiki/Holmium) | [Erbium](https://en.wikipedia.org/wiki/Erbium) | [Thulium](https://en.wikipedia.org/wiki/Thulium) | [Ytterbium](https://en.wikipedia.org/wiki/Ytterbium) | [Lutetium](https://en.wikipedia.org/wiki/Lutetium) | [Hafnium](https://en.wikipedia.org/wiki/Hafnium) | [Tantalum](https://en.wikipedia.org/wiki/Tantalum) | [Tungsten](https://en.wikipedia.org/wiki/Tungsten) | [Rhenium](https://en.wikipedia.org/wiki/Rhenium) | [Osmium](https://en.wikipedia.org/wiki/Osmium) | [Iridium](https://en.wikipedia.org/wiki/Iridium) | [Platinum](https://en.wikipedia.org/wiki/Platinum) | [Gold](https://en.wikipedia.org/wiki/Gold) | [Mercury (element)](https://en.wikipedia.org/wiki/Mercury_(element)) | [Thallium](https://en.wikipedia.org/wiki/Thallium) | [Lead](https://en.wikipedia.org/wiki/Lead) | [Bismuth](https://en.wikipedia.org/wiki/Bismuth) | [Polonium](https://en.wikipedia.org/wiki/Polonium) | [Astatine](https://en.wikipedia.org/wiki/Astatine) | [Radon](https://en.wikipedia.org/wiki/Radon) | | [Francium](https://en.wikipedia.org/wiki/Francium) | [Radium](https://en.wikipedia.org/wiki/Radium) | [Actinium](https://en.wikipedia.org/wiki/Actinium) | [Thorium](https://en.wikipedia.org/wiki/Thorium) | [Protactinium](https://en.wikipedia.org/wiki/Protactinium) | [Uranium](https://en.wikipedia.org/wiki/Uranium) | [Neptunium](https://en.wikipedia.org/wiki/Neptunium) | [Plutonium](https://en.wikipedia.org/wiki/Plutonium) | [Americium](https://en.wikipedia.org/wiki/Americium) | [Curium](https://en.wikipedia.org/wiki/Curium) | [Berkelium](https://en.wikipedia.org/wiki/Berkelium) | [Californium](https://en.wikipedia.org/wiki/Californium) | [Einsteinium](https://en.wikipedia.org/wiki/Einsteinium) | [Fermium](https://en.wikipedia.org/wiki/Fermium) | [Mendelevium](https://en.wikipedia.org/wiki/Mendelevium) | [Nobelium](https://en.wikipedia.org/wiki/Nobelium) | [Lawrencium](https://en.wikipedia.org/wiki/Lawrencium) | [Rutherfordium](https://en.wikipedia.org/wiki/Rutherfordium) | [Dubnium](https://en.wikipedia.org/wiki/Dubnium) | [Seaborgium](https://en.wikipedia.org/wiki/Seaborgium) | [Bohrium](https://en.wikipedia.org/wiki/Bohrium) | [Hassium](https://en.wikipedia.org/wiki/Hassium) | [Meitnerium](https://en.wikipedia.org/wiki/Meitnerium) | [Darmstadtium](https://en.wikipedia.org/wiki/Darmstadtium) | [Roentgenium](https://en.wikipedia.org/wiki/Roentgenium) | [Copernicium](https://en.wikipedia.org/wiki/Copernicium) | [Nihonium](https://en.wikipedia.org/wiki/Nihonium) | [Flerovium](https://en.wikipedia.org/wiki/Flerovium) | [Moscovium](https://en.wikipedia.org/wiki/Moscovium) | [Livermorium](https://en.wikipedia.org/wiki/Livermorium) | [Tennessine](https://en.wikipedia.org/wiki/Tennessine) | [Oganesson](https://en.wikipedia.org/wiki/Oganesson) | | [N](https://en.wikipedia.org/wiki/Nitrogen) ↑ **P** ↓ [As](https://en.wikipedia.org/wiki/Arsenic) | | [silicon](https://en.wikipedia.org/wiki/Silicon) ← **phosphorus** → [sulfur](https://en.wikipedia.org/wiki/Sulfur) | | | | |
| [**Atomic number**](https://en.wikipedia.org/wiki/Atomic_number)(*Z*) | 15 |
| [**Group**](https://en.wikipedia.org/wiki/Group_(periodic_table)) | [group 15 (pnictogens)](https://en.wikipedia.org/wiki/Pnictogen) |
| [**Period**](https://en.wikipedia.org/wiki/Period_(periodic_table)) | [period 3](https://en.wikipedia.org/wiki/Period_(periodic_table)#Period_3) |
| [**Block**](https://en.wikipedia.org/wiki/Block_(periodic_table)) | [p-block](https://en.wikipedia.org/wiki/P-block) |
| [**Element category**](https://en.wikipedia.org/wiki/Names_for_sets_of_chemical_elements#Category) | [reactive nonmetal](https://en.wikipedia.org/wiki/Reactive_nonmetal) |
| [**Electron configuration**](https://en.wikipedia.org/wiki/Electron_configuration) | [[Ne](https://en.wikipedia.org/wiki/Neon)] 3s2 3p3 |
| Electrons per shell | 2, 8, 5 |
| **Physical properties** | |
| [**Phase**](https://en.wikipedia.org/wiki/Phase_(matter)) **at**[**STP**](https://en.wikipedia.org/wiki/Standard_conditions_for_temperature_and_pressure) | [solid](https://en.wikipedia.org/wiki/Solid) |
| [**Melting point**](https://en.wikipedia.org/wiki/Melting_point) | white: 317.3 [K](https://en.wikipedia.org/wiki/Kelvin) ​(44.15 °C, ​111.5 °F)  red: ∼860 K (∼590 °C, ∼1090 °F)[[2]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-2) |
| [**Boiling point**](https://en.wikipedia.org/wiki/Boiling_point) | white: 553.7 K ​(280.5 °C, ​536.9 °F) |
| [**Density**](https://en.wikipedia.org/wiki/Density)(near r.t.) | white: 1.823 g/cm3 red: ≈2.2–2.34 g/cm3  violet: 2.36 g/cm3  black: 2.69 g/cm3 |
| [**Heat of fusion**](https://en.wikipedia.org/wiki/Enthalpy_of_fusion) | white: 0.66 [kJ/mol](https://en.wikipedia.org/wiki/Kilojoule_per_mole) |
| [**Heat of vaporisation**](https://en.wikipedia.org/wiki/Enthalpy_of_vaporization) | white: 51.9 kJ/mol |
| [**Molar heat capacity**](https://en.wikipedia.org/wiki/Molar_heat_capacity) | white: 23.824 J/(mol·K) |
| [**Vapour pressure**](https://en.wikipedia.org/wiki/Vapor_pressure) (white)   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | ***P***(Pa) | **1** | **10** | **100** | **1 k** | **10 k** | **100 k** | | **at *T***(K) | 279 | 307 | 342 | 388 | 453 | 549 | | |
| **Vapour pressure** (red, b.p. 431 °C)   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | ***P***(Pa) | **1** | **10** | **100** | **1 k** | **10 k** | **100 k** | | **at *T***(K) | 455 | 489 | 529 | 576 | 635 | 704 | | |
| **Atomic properties** | |
| [**Oxidation states**](https://en.wikipedia.org/wiki/Oxidation_state) | **−3**, −2, −1, +1,[[3]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-3) +2, **+3**, +4, **+5** (a mildly [acidic](https://en.wikipedia.org/wiki/Acidic) oxide) |
| [**Electronegativity**](https://en.wikipedia.org/wiki/Electronegativity) | Pauling scale: 2.19 |
| [**Ionisation energies**](https://en.wikipedia.org/wiki/Ionization_energy) | * 1st: 1011.8 kJ/mol * 2nd: 1907 kJ/mol * 3rd: 2914.1 kJ/mol * ([more](https://en.wikipedia.org/wiki/Molar_ionization_energies_of_the_elements#phosphorus)) |
| [**Covalent radius**](https://en.wikipedia.org/wiki/Covalent_radius) | 107±3 [pm](https://en.wikipedia.org/wiki/Picometre) |
| [**Van der Waals radius**](https://en.wikipedia.org/wiki/Van_der_Waals_radius) | 180 pm |
| [Color lines in a spectral range](https://en.wikipedia.org/wiki/File:Phosphorus_spectrum_visible.png)  [**Spectral lines**](https://en.wikipedia.org/wiki/Spectral_line) **of phosphorus** | |
| **Other properties** | |
| [**Crystal structure**](https://en.wikipedia.org/wiki/Crystal_structure) | ​[body-centred cubic](https://en.wikipedia.org/wiki/Cubic_crystal_system) (bcc)  [Bodycentredcubic crystal structure for phosphorus](https://en.wikipedia.org/wiki/File:Cubic-body-centered.svg) |
| [**Thermal conductivity**](https://en.wikipedia.org/wiki/Thermal_conductivity) | white: 0.236 W/(m·K)  black: 12.1 W/(m·K) |
| [**Magnetic ordering**](https://en.wikipedia.org/wiki/Magnetism) | white, red, violet, black: [diamagnetic](https://en.wikipedia.org/wiki/Diamagnetic)[[4]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-4) |
| [**Magnetic susceptibility**](https://en.wikipedia.org/wiki/Magnetic_susceptibility) | −20.8·10−6 cm3/mol (293 K)[[5]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-5) |
| [**Bulk modulus**](https://en.wikipedia.org/wiki/Bulk_modulus) | white: 5 GPa red: 11 GPa |
| [**CAS Number**](https://en.wikipedia.org/wiki/CAS_Registry_Number) | 7723-14-0 (red) 12185-10-3 (white) |
| **History** | |
| [**Discovery**](https://en.wikipedia.org/wiki/Timeline_of_chemical_element_discoveries) | [Hennig Brand](https://en.wikipedia.org/wiki/Hennig_Brand) (1669) |
| **Recognised as an element by** | [Antoine Lavoisier](https://en.wikipedia.org/wiki/Antoine_Lavoisier)[[6]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-6) (1777) |
| **Main** [**isotopes of phosphorus**](https://en.wikipedia.org/wiki/Isotopes_of_phosphorus) | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | [**Iso­tope**](https://en.wikipedia.org/wiki/Isotope) | [**Abun­dance**](https://en.wikipedia.org/wiki/Natural_abundance) | [**Half-life**](https://en.wikipedia.org/wiki/Half-life) **(*t*1/2)** | [**Decay mode**](https://en.wikipedia.org/wiki/Radioactive_decay) | [**Pro­duct**](https://en.wikipedia.org/wiki/Decay_product) | | **31P** | 100% | [stable](https://en.wikipedia.org/wiki/Stable_isotope) | | | | **32P** | [trace](https://en.wikipedia.org/wiki/Trace_radioisotope) | 14.28 d | [β−](https://en.wikipedia.org/wiki/Beta_emission) | [32S](https://en.wikipedia.org/wiki/Sulfur-32) | | **33P** | trace | 25.3 d | β− | [33S](https://en.wikipedia.org/wiki/Sulfur-33) | | |
| * [view](https://en.wikipedia.org/wiki/Template:Infobox_phosphorus) * [talk](https://en.wikipedia.org/wiki/Template_talk:Infobox_phosphorus) * [edit](https://en.wikipedia.org/w/index.php?title=Template:Infobox_phosphorus&action=edit)   | [references](https://en.wikipedia.org/wiki/List_of_data_references_for_chemical_elements) | |

**Phosphorus** is a [chemical element](https://en.wikipedia.org/wiki/Chemical_element) with symbol **P** and [atomic number](https://en.wikipedia.org/wiki/Atomic_number) 15. Elemental phosphorus exists in two major forms, [white phosphorus](https://en.wikipedia.org/wiki/White_phosphorus) and [red phosphorus](https://en.wikipedia.org/wiki/Red_phosphorus), but because it is highly [reactive](https://en.wikipedia.org/wiki/Reactivity_(chemistry)), phosphorus is never found as a free element on Earth. It has a concentration in the Earth's crust of about one gram per kilogram (compare copper at about 0.06 grams). With few exceptions, minerals containing phosphorus are in the maximally [oxidized](https://en.wikipedia.org/wiki/Redox) state as inorganic [phosphate rocks](https://en.wikipedia.org/wiki/Phosphate_minerals).

Elemental phosphorus was first isolated (as white phosphorus) in 1669 and emitted a faint glow when exposed to [oxygen](https://en.wikipedia.org/wiki/Oxygen) – hence the name, taken from Greek mythology, Φωσφόρος meaning "light-bearer" (Latin [*Lucifer*](https://en.wikipedia.org/wiki/Lucifer)), referring to the "[Morning Star](https://en.wikipedia.org/wiki/Phosphorus_(morning_star))", the planet [Venus](https://en.wikipedia.org/wiki/Venus). The term "[phosphorescence](https://en.wikipedia.org/wiki/Phosphorescence)", meaning glow after illumination, derives from this property of phosphorus, although the word has since been used for a different physical process that produces a glow. The glow of phosphorus is caused by [oxidation](https://en.wikipedia.org/wiki/Oxidation) of the white (but not red) phosphorus — a process now called [chemiluminescence](https://en.wikipedia.org/wiki/Chemiluminescence). Together with nitrogen, arsenic, antimony, and bismuth, phosphorus is classified as a [pnictogen](https://en.wikipedia.org/wiki/Pnictogen).

Phosphorus is essential for life. [Phosphates](https://en.wikipedia.org/wiki/Phosphate) (compounds containing the phosphate ion, PO43−) are a component of [DNA](https://en.wikipedia.org/wiki/DNA), [RNA](https://en.wikipedia.org/wiki/RNA), [ATP](https://en.wikipedia.org/wiki/Adenosine_triphosphate), and [phospholipids](https://en.wikipedia.org/wiki/Phospholipid). Elemental phosphorus was first isolated from human [urine](https://en.wikipedia.org/wiki/Urine), and [bone ash](https://en.wikipedia.org/wiki/Bone_ash) was an important early phosphate source. [Phosphate](https://en.wikipedia.org/wiki/Phosphate) mines contain fossils because phosphate is present in the fossilized deposits of animal remains and excreta. Low phosphate levels are an important limit to growth in some aquatic systems. The vast majority of phosphorus compounds mined are consumed as [fertilisers](https://en.wikipedia.org/wiki/Fertiliser). Phosphate is needed to replace the phosphorus that plants remove from the soil, and its annual demand is rising nearly twice as fast as the growth of the human population. Other applications include [organophosphorus compounds](https://en.wikipedia.org/wiki/Organophosphorus_compound) in [detergents](https://en.wikipedia.org/wiki/Detergent), [pesticides](https://en.wikipedia.org/wiki/Pesticide), and [nerve agents](https://en.wikipedia.org/wiki/Nerve_agent).



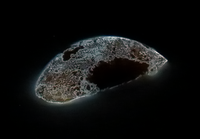
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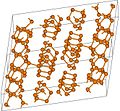
**Characteristics**

**Allotropes**

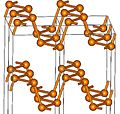
Main article: [Allotropes of phosphorus](https://en.wikipedia.org/wiki/Allotropes_of_phosphorus)

[](https://en.wikipedia.org/wiki/File:White_phosphorus_glowing_e17.png)

White phosphorus exposed to air glows in the dark

[](https://en.wikipedia.org/wiki/File:RedPhosphorus.jpg)

Crystal structure of red phosphorus

[](https://en.wikipedia.org/wiki/File:BlackPhosphorus.jpg)

Crystal structure of black phosphorus

Phosphorus has several [allotropes](https://en.wikipedia.org/wiki/Allotropy) that exhibit strikingly different properties.[[8]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-HW85-8) The two most common allotropes are **white phosphorus** and **red phosphorus**.[[9]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Abundance-9)

From the perspective of applications and chemical literature, the most important form of elemental phosphorus is [white phosphorus](https://en.wikipedia.org/wiki/Allotropes_of_phosphorus#White_phosphorus), often abbreviated as **WP**. It is a soft, waxy solid which consists of tetrahedral P  
4 molecules, in which each atom is bound to the other three atoms by a single bond. This P  
4 tetrahedron is also present in liquid and gaseous phosphorus up to the temperature of 800 °C (1,470 °F) when it starts decomposing to P  
2 molecules.[[10]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-10) White phosphorus exists in two crystalline forms: α (alpha) and β (beta). At room temperature, the α-form is stable, which is more common and it has cubic crystal structure and at 195.2 K (−78.0 °C), it transforms into β-form, which has hexagonal crystal structure. These forms differ in terms of the relative orientations of the constituent P4 tetrahedra.[[11]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-11)[[12]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-12)

White phosphorus is the least stable, the most reactive, the most [volatile](https://en.wikipedia.org/wiki/Volatility_(chemistry)), the least [dense](https://en.wikipedia.org/wiki/Density), and the most toxic of the allotropes. White phosphorus gradually changes to red phosphorus. This transformation is accelerated by light and heat, and samples of white phosphorus almost always contain some red phosphorus and accordingly appear yellow. For this reason, white phosphorus that is aged or otherwise impure (e.g., weapons-grade, not lab-grade WP) is also called **yellow phosphorus**. When exposed to oxygen, white phosphorus glows in the dark with a very faint tinge of green and blue. It is highly [flammable](https://en.wikipedia.org/wiki/Flammable) and [pyrophoric](https://en.wikipedia.org/wiki/Pyrophoricity) (self-igniting) upon contact with air. Owing to its pyrophoricity, white phosphorus is used as an additive in [napalm](https://en.wikipedia.org/wiki/Napalm). The odour of combustion of this form has a characteristic garlic smell, and samples are commonly coated with white "[phosphorus pentoxide](https://en.wikipedia.org/wiki/Phosphorus_pentoxide)", which consists of P  
4O  
10 tetrahedra with oxygen inserted between the phosphorus atoms and at their vertices. White phosphorus is insoluble in water but soluble in carbon disulfide.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13)

[Thermolysis](https://en.wikipedia.org/wiki/Thermal_decomposition) of P4 at 1100 kelvin gives [diphosphorus](https://en.wikipedia.org/wiki/Diphosphorus), P2. This species is not stable as a solid or liquid. The dimeric unit contains a triple bond and is analogous to N2. It can also be generated as a transient intermediate in solution by thermolysis of organophosphorus precursor reagents.[[14]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-14) At still higher temperatures, P2 dissociates into atomic P.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13)

[Red phosphorus](https://en.wikipedia.org/wiki/Red_phosphorus) is polymeric in structure. It can be viewed as a derivative of P4 wherein one P-P bond is broken, and one additional bond is formed with the neighbouring tetrahedron resulting in a chain-like structure. Red phosphorus may be formed by heating white phosphorus to 250 °C (482 °F) or by exposing white phosphorus to sunlight.[[15]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-mellor-717-15) Phosphorus after this treatment is [amorphous](https://en.wikipedia.org/wiki/Amorphous). Upon further heating, this material crystallises. In this sense, red phosphorus is not an allotrope, but rather an intermediate phase between the white and violet phosphorus, and most of its properties have a range of values. For example, freshly prepared, bright red phosphorus is highly reactive and ignites at about 300 °C (572 °F),[[16]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-wiberg-16) though it is more stable than white phosphorus, which ignites at about 30 °C (86 °F).[[17]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-mellor-721-722-17) After prolonged heating or storage, the color darkens (see infobox images); the resulting product is more stable and does not spontaneously ignite in air.[[18]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-CRC-18)

[Violet phosphorus](https://en.wikipedia.org/wiki/Violet_phosphorus) is a form of phosphorus that can be produced by day-long annealing of red phosphorus above 550 °C. In 1865, [Hittorf](https://en.wikipedia.org/wiki/Hittorf) discovered that when phosphorus was recrystallised from molten [lead](https://en.wikipedia.org/wiki/Lead), a red/purple form is obtained. Therefore, this form is sometimes known as "Hittorf's phosphorus" (or violet or α-metallic phosphorus).[[19]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-berger-19)

[Black phosphorus](https://en.wikipedia.org/wiki/Black_phosphorus) is the least reactive allotrope and the thermodynamically stable form below 550 °C (1,022 °F). It is also known as β-metallic phosphorus and has a structure somewhat resembling that of [graphite](https://en.wikipedia.org/wiki/Graphite).[[20]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Brown-20)[[21]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-21) It is obtained by heating white phosphorus under high pressures (about 12,000 standard atmospheres or 1.2 gigapascals). It can also be produced at ambient conditions using metal salts, e.g. mercury, as catalysts.[[22]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-22) In appearance, properties, and structure, it resembles [graphite](https://en.wikipedia.org/wiki/Graphite), being black and flaky, a conductor of electricity, and has puckered sheets of linked atoms.[[23]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-23)

Another form, scarlet phosphorus, is obtained by allowing a solution of white phosphorus in [carbon disulfide](https://en.wikipedia.org/wiki/Carbon_disulfide) to evaporate in [sunlight](https://en.wikipedia.org/wiki/Sunlight).[[19]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-berger-19)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Properties of some allotropes of phosphorus[[8]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-HW85-8)[[19]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-berger-19) | | | | |
| **Form** | **white(α)** | **white(β)** | **violet** | **black** |
| **Symmetry** | [Body-centred cubic](https://en.wikipedia.org/wiki/Cubic_crystal_system) | [Triclinic](https://en.wikipedia.org/wiki/Triclinic) | [Monoclinic](https://en.wikipedia.org/wiki/Monoclinic) | [Orthorhombic](https://en.wikipedia.org/wiki/Orthorhombic) |
| [**Pearson symbol**](https://en.wikipedia.org/wiki/Pearson_symbol) |  | aP24 | mP84 | oS8 |
| [**Space group**](https://en.wikipedia.org/wiki/Space_group) | I43m | P1 No.2 | P2/c No.13 | Cmca No.64 |
| [**Density**](https://en.wikipedia.org/wiki/Density) **(g/cm3)** | 1.828 | 1.88 | 2.36 | 2.69 |
| [**Band gap**](https://en.wikipedia.org/wiki/Band_gap) **(eV)** | 2.1 |  | 1.5 | 0.34 |
| [**Refractive index**](https://en.wikipedia.org/wiki/Refractive_index) | 1.8244 |  | 2.6 | 2.4 |

**Chemiluminescence**

When first isolated, it was observed that the green glow emanating from white phosphorus would persist for a time in a stoppered jar, but then cease. [Robert Boyle](https://en.wikipedia.org/wiki/Robert_Boyle) in the 1680s ascribed it to "debilitation" of the air. Actually, it is oxygen being consumed. By the 18th century, it was known that in pure oxygen, phosphorus does not glow at all;[[24]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-24) there is only a range of [partial pressures](https://en.wikipedia.org/wiki/Partial_pressure) at which it does. Heat can be applied to drive the reaction at higher pressures.[[25]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-25)

In 1974, the glow was explained by R. J. van Zee and A. U. Khan.[[26]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-shockinghistory-26)[[27]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-27) A reaction with oxygen takes place at the surface of the solid (or liquid) phosphorus, forming the short-lived molecules HPO and P  
2O  
2 that both emit visible light. The reaction is slow and only very little of the intermediates are required to produce the luminescence, hence the extended time the glow continues in a stoppered jar.

Since its discovery, [*phosphors*](https://en.wikipedia.org/wiki/Phosphor) and [*phosphorescence*](https://en.wikipedia.org/wiki/Phosphorescence) were used loosely to describe substances that shine in the dark without burning. Although the term [phosphorescence](https://en.wikipedia.org/wiki/Phosphorescence) is derived from phosphorus, the reaction that gives phosphorus its glow is properly called [chemiluminescence](https://en.wikipedia.org/wiki/Chemiluminescence) (glowing due to a cold chemical reaction), not phosphorescence (re-emitting light that previously fell onto a substance and excited it).[[28]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-sommers-28)

**Isotopes**

Main article: [Isotopes of phosphorus](https://en.wikipedia.org/wiki/Isotopes_of_phosphorus)

Twenty-three [isotopes](https://en.wikipedia.org/wiki/Isotopes) of phosphorus are known,[[29]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-29) including all possibilities from 24  
P up to 46  
P. Only 31  
P is stable and is therefore present at 100% abundance. The half-integer [nuclear spin](https://en.wikipedia.org/wiki/Nuclear_spin) and high abundance of 31P make [phosphorus-31 NMR](https://en.wikipedia.org/wiki/Phosphorus-31_NMR) spectroscopy a very useful analytical tool in studies of phosphorus-containing samples.

Two [radioactive isotopes](https://en.wikipedia.org/wiki/Radioactive_isotope) of phosphorus have half-lives suitable for biological scientific experiments. These are:

* 32  
  P, a [beta](https://en.wikipedia.org/wiki/Beta_particle)-emitter (1.71 MeV) with a [half-life](https://en.wikipedia.org/wiki/Half-life) of 14.3 days, which is used routinely in life-science laboratories, primarily to produce [radiolabeled](https://en.wikipedia.org/wiki/Radiolabel) DNA and RNA [probes](https://en.wikipedia.org/wiki/Hybridization_probe), *e.g.* for use in [Northern blots](https://en.wikipedia.org/wiki/Northern_blot) or [Southern blots](https://en.wikipedia.org/wiki/Southern_blot).
* 33  
  P, a beta-emitter (0.25 MeV) with a half-life of 25.4 days. It is used in life-science laboratories in applications in which lower energy beta emissions are advantageous such as [DNA](https://en.wikipedia.org/wiki/DNA) sequencing.

The high energy beta particles from 32  
P penetrate skin and [corneas](https://en.wikipedia.org/wiki/Cornea) and any 32  
P ingested, inhaled, or absorbed is readily incorporated into bone and [nucleic acids](https://en.wikipedia.org/wiki/Nucleic_acid). For these reasons, [Occupational Safety and Health Administration](https://en.wikipedia.org/wiki/Occupational_Safety_and_Health_Administration) in the United States, and similar institutions in other developed countries require personnel working with 32  
P to wear lab coats, disposable gloves, and safety glasses or goggles to protect the eyes, and avoid working directly over open containers. [Monitoring](https://en.wikipedia.org/wiki/Biomonitoring) personal, clothing, and surface contamination is also required. [Shielding](https://en.wikipedia.org/wiki/Radiation_protection) requires special consideration. The high energy of the beta particles gives rise to secondary emission of [X-rays](https://en.wikipedia.org/wiki/X-ray) via [Bremsstrahlung](https://en.wikipedia.org/wiki/Bremsstrahlung) (braking radiation) in dense shielding materials such as lead. Therefore, the radiation must be shielded with low density materials such as acrylic or other plastic, water, or (when transparency is not required), even wood.[[30]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-30)

**Occurrence**

See also: [Category:Phosphate minerals](https://en.wikipedia.org/wiki/Category:Phosphate_minerals).

**Universe**

In 2013, astronomers detected phosphorus in [Cassiopeia A](https://en.wikipedia.org/wiki/Cassiopeia_A), which confirmed that this element is produced in [supernovae](https://en.wikipedia.org/wiki/Supernova) as a byproduct of [supernova nucleosynthesis](https://en.wikipedia.org/wiki/Supernova_nucleosynthesis). The phosphorus-to-[iron](https://en.wikipedia.org/wiki/Iron) ratio in material from the [supernova remnant](https://en.wikipedia.org/wiki/Supernova_remnant) could be up to 100 times higher than in the [Milky Way](https://en.wikipedia.org/wiki/Milky_Way) in general.[[31]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-31)

**Crust and organic sources**

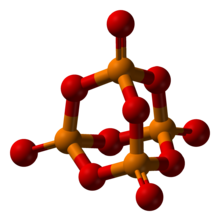
Phosphorus has a concentration in the Earth's crust of about one gram per kilogram (compare copper at about 0.06 grams). It is not found free in nature, but is widely distributed in many [minerals](https://en.wikipedia.org/wiki/Mineral), usually as phosphates.[[9]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Abundance-9) Inorganic [phosphate rock](https://en.wikipedia.org/wiki/Phosphate_rock), which is partially made of [apatite](https://en.wikipedia.org/wiki/Apatite) (a group of minerals being, generally, pentacalcium triorthophosphate fluoride (hydroxide)), is today the chief commercial source of this element. According to the [US Geological Survey (USGS)](https://en.wikipedia.org/wiki/US_Geological_Survey), about 50 percent of the global phosphorus reserves are in the Arab nations.[[32]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-USGS-32) Large deposits of apatite are located in [China](https://en.wikipedia.org/wiki/People%27s_Republic_of_China), [Russia](https://en.wikipedia.org/wiki/Russia), [Morocco](https://en.wikipedia.org/wiki/Morocco),[[33]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-MJ-33) [Florida](https://en.wikipedia.org/wiki/Florida), [Idaho](https://en.wikipedia.org/wiki/Idaho), [Tennessee](https://en.wikipedia.org/wiki/Tennessee), [Utah](https://en.wikipedia.org/wiki/Utah), and elsewhere.[[34]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-34) [Albright and Wilson](https://en.wikipedia.org/wiki/Albright_and_Wilson) in the UK and their [Niagara Falls](https://en.wikipedia.org/wiki/Niagara_Falls) plant, for instance, were using phosphate rock in the 1890s and 1900s from Tennessee, Florida, and the [Îles du Connétable](https://en.wikipedia.org/wiki/%C3%8Eles_du_Conn%C3%A9table) ([guano](https://en.wikipedia.org/wiki/Guano) island sources of phosphate); by 1950, they were using phosphate rock mainly from Tennessee and North Africa.[[35]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-51-35)

Organic sources, namely [urine](https://en.wikipedia.org/wiki/Urine), [bone ash](https://en.wikipedia.org/wiki/Bone_ash) and (in the latter 19th century) [guano](https://en.wikipedia.org/wiki/Guano), were historically of importance but had only limited commercial success.[[36]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-36) As urine contains phosphorus, it has fertilising qualities which are still harnessed today in some countries, including [Sweden](https://en.wikipedia.org/wiki/Sweden), using methods for [reuse of excreta](https://en.wikipedia.org/wiki/Reuse_of_excreta). To this end, urine can be used as a fertiliser in its pure form or part of being mixed with water in the form of [sewage](https://en.wikipedia.org/wiki/Sewage) or [sewage sludge](https://en.wikipedia.org/wiki/Sewage_sludge).

**Compounds**

See also: the categories [Phosphate minerals](https://en.wikipedia.org/wiki/Category:Phosphate_minerals) and [Phosphorus compounds](https://en.wikipedia.org/wiki/Category:Phosphorus_compounds).

**Phosphorus(V)**

[](https://en.wikipedia.org/wiki/File:Phosphorus-pentoxide-3D-balls.png)

The tetrahedral structure of P4O10 and P4S10.

The most prevalent compounds of phosphorus are derivatives of phosphate (PO43−), a tetrahedral anion.[[37]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-37) Phosphate is the conjugate base of phosphoric acid, which is produced on a massive scale for use in fertilisers. Being triprotic, phosphoric acid converts stepwise to three conjugate bases:

H3PO4 + H2O ⇌ H3O+ + H2PO4−       *K*a1= 7.25×10−3

H2PO4− + H2O ⇌ H3O+ + HPO42−       *K*a2= 6.31×10−8

HPO42− + H2O ⇌ H3O+ +  PO43−        *K*a3= 3.98×10−13

Phosphate exhibits a tendency to form chains and rings containing P-O-P bonds. Many polyphosphates are known, including [ATP](https://en.wikipedia.org/wiki/Adenosine_triphosphate). Polyphosphates arise by dehydration of hydrogen phosphates such as HPO42− and H2PO4−. For example, the industrially important pentasodium triphosphate (also known as [sodium tripolyphosphate](https://en.wikipedia.org/wiki/Sodium_tripolyphosphate), STPP) is produced industrially on by the megatonne by this [condensation reaction](https://en.wikipedia.org/wiki/Condensation_reaction):

2 Na2[(HO)PO3] + Na[(HO)2PO2] → Na5[O3P-O-P(O)2-O-PO3] + 2 H2O

[Phosphorus pentoxide](https://en.wikipedia.org/wiki/Phosphorus_pentoxide) (P4O10) is the [acid anhydride](https://en.wikipedia.org/wiki/Acid_anhydride) of phosphoric acid, but several intermediates between the two are known. This waxy white solid reacts vigorously with water.

With metal [cations](https://en.wikipedia.org/wiki/Cation), phosphate forms a variety of salts. These solids are polymeric, featuring P-O-M linkages. When the metal cation has a charge of 2+ or 3+, the salts are generally insoluble, hence they exist as common minerals. Many phosphate salts are derived from hydrogen phosphate (HPO42−).

[PCl5](https://en.wikipedia.org/wiki/Phosphorus_pentachloride) and [PF5](https://en.wikipedia.org/wiki/Phosphorus_pentafluoride) are common compounds. PF5 is a colourless gas and the molecules have [trigonal bipyramidal](https://en.wikipedia.org/wiki/Trigonal_bipyramid) geometry. PCl5 is a colourless solid which has an ionic formulation of PCl4+ PCl6−, but adopts the [trigonal bipyramidal](https://en.wikipedia.org/wiki/Trigonal_bipyramid) geometry when molten or in the vapour phase.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13) [PBr5](https://en.wikipedia.org/wiki/Phosphorus_pentabromide) is an unstable solid formulated as PBr4+Br−and [PI5](https://en.wikipedia.org/wiki/Phosphorus_pentaiodide) is not known.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13) The pentachloride and pentafluoride are [Lewis acids](https://en.wikipedia.org/wiki/Lewis_acid). With fluoride, PF5 forms PF6−, an [anion](https://en.wikipedia.org/wiki/Anion) that is [isoelectronic](https://en.wikipedia.org/wiki/Isoelectronic) with SF6. The most important oxyhalide is [phosphorus oxychloride](https://en.wikipedia.org/wiki/Phosphorus_oxychloride), (POCl3), which is approximately tetrahedral.

Before extensive computer calculations were feasible, it was thought that bonding in phosphorus(V) compounds involved *d* orbitals. Computer modeling of [molecular orbital theory](https://en.wikipedia.org/wiki/Molecular_orbital_theory) indicates that this bonding involves only s- and p-orbitals.[[38]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-38)

**Phosphorus(III)**

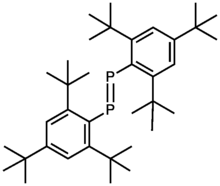
All four symmetrical trihalides are well known: gaseous [PF3](https://en.wikipedia.org/wiki/Phosphorus_trifluoride), the yellowish liquids [PCl3](https://en.wikipedia.org/wiki/Phosphorus_trichloride) and [PBr3](https://en.wikipedia.org/wiki/Phosphorus_tribromide), and the solid [PI3](https://en.wikipedia.org/wiki/Phosphorus_triiodide). These materials are moisture sensitive, hydrolysing to give [phosphorous acid](https://en.wikipedia.org/wiki/Phosphorous_acid). The trichloride, a common reagent, is produced by chlorination of white phosphorus:

P4 + 6 Cl2 → 4 PCl3

The trifluoride is produced from the trichloride by halide exchange. PF3 is toxic because it binds to [haemoglobin](https://en.wikipedia.org/wiki/Haemoglobin).

[Phosphorus(III) oxide](https://en.wikipedia.org/wiki/Phosphorus_trioxide), P4O6 (also called tetraphosphorus hexoxide) is the anhydride of P(OH)3, the minor tautomer of phosphorous acid. The structure of P4O6 is like that of P4O10 without the terminal oxide groups.

**Phosphorus(I) and phosphorus(II)**

[](https://en.wikipedia.org/wiki/File:YoshifujiR2P2.png)

A stable [diphosphene](https://en.wikipedia.org/wiki/Diphosphene), a derivative of phosphorus(I).

These compounds generally feature P-P bonds.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13) Examples include catenated derivatives of phosphine and organophosphines. Compounds containing P=P double bonds have also been observed, although they are rare.

**Phosphides and phosphines**

Phosphides arise by reaction of metals with red phosphorus. The alkali metals (group 1) and alkaline earth metals can form ionic compounds containing the [phosphide](https://en.wikipedia.org/wiki/Phosphide) ion, P3−. These compounds react with water to form [phosphine](https://en.wikipedia.org/wiki/Phosphine). Other phosphides, for example Na3P7, are known for these reactive metals. With the transition metals as well as the monophosphides there are metal-rich phosphides, which are generally hard refractory compounds with a metallic lustre, and phosphorus-rich phosphides which are less stable and include semiconductors.[[39]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-39) [Schreibersite](https://en.wikipedia.org/wiki/Schreibersite) is a naturally occurring metal-rich phosphide found in meteorites. The structures of the metal-rich and phosphorus-rich phosphides can be complex.

[Phosphine](https://en.wikipedia.org/wiki/Phosphine) (PH3) and its organic derivatives (PR3) are structural analogues of ammonia (NH3), but the bond angles at phosphorus are closer to 90° for phosphine and its organic derivatives. It is an ill-smelling, toxic compound. Phosphorus has an oxidation number of -3 in phosphine. Phosphine is produced by hydrolysis of [calcium phosphide](https://en.wikipedia.org/wiki/Calcium_phosphide), Ca3P2. Unlike ammonia, phosphine is oxidised by air. Phosphine is also far less basic than ammonia. Other phosphines are known which contain chains of up to nine phosphorus atoms and have the formula PnHn+2.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13) The highly flammable gas [diphosphine](https://en.wikipedia.org/wiki/Diphosphine) (P2H4) is an analogue of [hydrazine](https://en.wikipedia.org/wiki/Hydrazine).

**Oxoacids**

Phosphorous oxoacids are extensive, often commercially important, and sometimes structurally complicated. They all have acidic protons bound to oxygen atoms, some have nonacidic protons that are bonded directly to phosphorus and some contain phosphorus - phosphorus bonds.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13) Although many oxoacids of phosphorus are formed, only nine are commercially important, and three of them, [hypophosphorous acid](https://en.wikipedia.org/wiki/Hypophosphorous_acid), [phosphorous acid](https://en.wikipedia.org/wiki/Phosphorous_acid), and phosphoric acid, are particularly important.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Oxidation state** | **Formula** | **Name** | **Acidic protons** | **Compounds** |
| +1 | HH2PO2 | [hypophosphorous acid](https://en.wikipedia.org/wiki/Hypophosphorous_acid) | 1 | acid, salts |
| +3 | H2HPO3 | [phosphorous acid](https://en.wikipedia.org/wiki/Phosphorous_acid) | 2 | acid, salts |
| +3 | HPO2 | [metaphosphorous acid](https://en.wikipedia.org/w/index.php?title=Metaphosphorous_acid&action=edit&redlink=1) | 1 | salts |
| +3 | H3PO3 | (ortho)[phosphorous acid](https://en.wikipedia.org/wiki/Phosphorous_acid) | 3 | acid, salts |
| +4 | H4P2O6 | [hypophosphoric acid](https://en.wikipedia.org/wiki/Hypophosphoric_acid) | 4 | acid, salts |
| +5 | (HPO3)n | [metaphosphoric acids](https://en.wikipedia.org/wiki/Metaphosphoric_acid) | n | salts (n=3,4,6) |
| +5 | H(HPO3)nOH | [polyphosphoric acids](https://en.wikipedia.org/wiki/Polyphosphoric_acid) | n+2 | acids, salts (n=1-6) |
| +5 | H5P3O10 | [tripolyphosphoric acid](https://en.wikipedia.org/wiki/Tripolyphosphoric_acid) | 3 | salts |
| +5 | H4P2O7 | [pyrophosphoric acid](https://en.wikipedia.org/wiki/Pyrophosphoric_acid) | 4 | acid, salts |
| +5 | H3PO4 | (ortho)[phosphoric acid](https://en.wikipedia.org/wiki/Phosphoric_acid) | 3 | acid, salts |

**Nitrides**

The PN molecule is considered unstable, but is a product of crystalline [phosphorus nitride](https://en.wikipedia.org/wiki/Triphosphorus_pentanitride) decomposition at 1100 K. Similarly, H2PN is considered unstable, and phosphorus nitride halogens like F2PN, Cl2PN, Br2PN, and I2PN oligomerise into cyclic [Polyphosphazenes](https://en.wikipedia.org/wiki/Polyphosphazene). For example, compounds of the formula (PNCl2)n exist mainly as rings such as the [trimer](https://en.wikipedia.org/wiki/Trimer_(chemistry)) [hexachlorophosphazene](https://en.wikipedia.org/wiki/Hexachlorophosphazene). The phosphazenes arise by treatment of phosphorus pentachloride with ammonium chloride:

PCl5 + NH4Cl → 1/*n* (NPCl2)*n* + 4 HCl

When the chloride groups are replaced by [alkoxide](https://en.wikipedia.org/wiki/Alkoxide) (RO−), a family of polymers is produced with potentially useful properties.[[40]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-40)

**Sulfides**

Main article: [phosphorus sulfide](https://en.wikipedia.org/wiki/Phosphorus_sulfide)

Phosphorus forms a wide range of sulfides, where the phosphorus can be in P(V), P(III) or other oxidation states. The most famous is the three-fold symmetric P4S3 which is used in strike-anywhere matches. P4S10 and P4O10 have analogous structures.[[41]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-41) Mixed oxyhalides and oxyhydrides of phosphorus(III) are almost unknown.

**Organophosphorus compounds**

Main article: [organophosphorus compounds](https://en.wikipedia.org/wiki/Organophosphorus_compounds)

Compounds with P-C and P-O-C bonds are often classified as organophosphorus compounds. They are widely used commercially. The PCl3 serves as a source of P3+ in routes to organophosphorus(III) compounds. For example, it is the precursor to [triphenylphosphine](https://en.wikipedia.org/wiki/Triphenylphosphine):

PCl3 + 6 Na + 3 C6H5Cl → P(C6H5)3 + 6 NaCl

Treatment of phosphorus trihalides with alcohols and [phenols](https://en.wikipedia.org/wiki/Phenol) gives phosphites, e.g. [triphenylphosphite](https://en.wikipedia.org/wiki/Triphenylphosphite):

PCl3 + 3 C6H5OH → P(OC6H5)3 + 3 HCl

Similar reactions occur for [phosphorus oxychloride](https://en.wikipedia.org/wiki/Phosphorus_oxychloride), affording [triphenylphosphate](https://en.wikipedia.org/wiki/Triphenylphosphate):

OPCl3 + 3 C6H5OH → OP(OC6H5)3 + 3 HCl

**History**

The name *Phosphorus* in Ancient Greece was the name for the planet [Venus](https://en.wikipedia.org/wiki/Venus) and is derived from the [Greek](https://en.wikipedia.org/wiki/Greek_language) words (φῶς = light, φέρω = carry), which roughly translates as light-bringer or light carrier.[[15]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-mellor-717-15) (In [Greek mythology](https://en.wikipedia.org/wiki/Greek_mythology) and tradition, Augerinus (Αυγερινός = morning star, still in use today), Hesperus or Hesperinus (΄Εσπερος or Εσπερινός or Αποσπερίτης = evening star, still in use today) and Eosphorus (Εωσφόρος = dawnbearer, not in use for the planet after Christianity) are close homologues, and also associated with Phosphorus-the-planet).

According to the Oxford English Dictionary, the correct spelling of the element is **phosphorus**. The word **phosphorous** is the adjectival form of the P3+ valence: so, just as [sulfur](https://en.wikipedia.org/wiki/Sulfur) forms sulfur**ous** and sulfur**ic** compounds, phosphor**us** forms phosphor**ous** compounds (e.g., [phosphorous acid](https://en.wikipedia.org/wiki/Phosphorous_acid)) and P5+ valence phosphor**ic** compounds (e.g., [phosphoric acids and phosphates](https://en.wikipedia.org/wiki/Phosphoric_acids_and_phosphates)).

**Discovery**

[](https://en.wikipedia.org/wiki/File:Robert_boyle.jpg)

[Robert Boyle](https://en.wikipedia.org/wiki/Robert_Boyle)

The discovery of phosphorus, the first element to be discovered that was not known since ancient times,[[42]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-42) is credited to the German alchemist [Hennig Brand](https://en.wikipedia.org/wiki/Hennig_Brand) in 1669, although other chemists might have discovered phosphorus around the same time.[[43]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-disc-43) Brand experimented with [urine](https://en.wikipedia.org/wiki/Urine), which contains considerable quantities of dissolved phosphates from normal metabolism.[[15]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-mellor-717-15) Working in [Hamburg](https://en.wikipedia.org/wiki/Hamburg), Brand attempted to create the fabled [philosopher's stone](https://en.wikipedia.org/wiki/Philosopher%27s_stone) through the [distillation](https://en.wikipedia.org/wiki/Distillation) of some [salts](https://en.wikipedia.org/wiki/Salt_(chemistry)) by evaporating urine, and in the process produced a white material that glowed in the dark and burned brilliantly. It was named *phosphorus mirabilis* ("miraculous bearer of light").[[44]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-schmundt-44)

Brand's process originally involved letting urine stand for days until it gave off a terrible smell. Then he boiled it down to a paste, heated this paste to a high temperature, and led the vapours through water, where he hoped they would condense to gold. Instead, he obtained a white, waxy substance that glowed in the dark. Brand had discovered phosphorus. We now know that Brand produced ammonium sodium hydrogen phosphate, (NH  
4)NaHPO  
4. While the quantities were essentially correct (it took about 1,100 litres [290 US gal] of urine to make about 60 g of phosphorus), it was unnecessary to allow the urine to rot first. Later scientists discovered that fresh urine yielded the same amount of phosphorus.[[28]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-sommers-28)

Brand at first tried to keep the method secret,[[45]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-45) but later sold the recipe for 200 thalers to D. Krafft from Dresden,[[15]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-mellor-717-15) who could now make it as well, and toured much of Europe with it, including England, where he met with [Robert Boyle](https://en.wikipedia.org/wiki/Robert_Boyle). The secret that it was made from urine leaked out and first [Johann Kunckel](https://en.wikipedia.org/wiki/Johann_von_L%C3%B6wenstern-Kunckel) (1630–1703) in Sweden (1678) and later Boyle in London (1680) also managed to make phosphorus, possibly with the aid of his assistant, [Ambrose Godfrey-Hanckwitz](https://en.wikipedia.org/wiki/Ambrose_Godfrey), who later made a business of the manufacture of phosphorus.

Boyle states that Krafft gave him no information as to the preparation of phosphorus other than that it was derived from "somewhat that belonged to the body of man". This gave Boyle a valuable clue, so that he, too, managed to make phosphorus, and published the method of its manufacture.[[15]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-mellor-717-15) Later he improved Brand's process by using sand in the reaction (still using urine as base material),

4 NaPO  
3 + 2 SiO  
2 + 10 C → 2 Na  
2SiO  
3 + 10 CO + P  
4

Robert Boyle was the first to use phosphorus to ignite sulfur-tipped wooden splints, forerunners of our modern matches, in 1680.[[46]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-46)

Phosphorus was the 13th element to be discovered. For this reason, and due to its use in explosives, poisons and nerve agents, it is sometimes referred to as "the Devil's element".[[47]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-47)

**Bone ash and guano**

[](https://en.wikipedia.org/wiki/File:DSCN5766-guano-glantz_crop_b.jpg)

[Guano](https://en.wikipedia.org/wiki/Guano) mining in the Central [Chincha Islands](https://en.wikipedia.org/wiki/Chincha_Islands), ca. 1860.

In 1769, [Johan Gottlieb Gahn](https://en.wikipedia.org/wiki/Johan_Gottlieb_Gahn) and [Carl Wilhelm Scheele](https://en.wikipedia.org/wiki/Carl_Wilhelm_Scheele) showed that calcium phosphate (Ca  
3(PO  
4)  
2) is found in bones, and they obtained elemental phosphorus from [bone ash](https://en.wikipedia.org/wiki/Bone_ash). [Antoine Lavoisier](https://en.wikipedia.org/wiki/Antoine_Lavoisier) recognised phosphorus as an element in 1777.[[48]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-48) Bone ash was the major source of phosphorus until the 1840s. The method started by roasting bones, then employed the use of clay [retorts](https://en.wikipedia.org/wiki/Retorts) encased in a very hot brick furnace to distill out the highly toxic elemental phosphorus product.[[49]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-49) Alternately, precipitated phosphates could be made from ground-up bones that had been de-greased and treated with strong acids. White phosphorus could then be made by heating the precipitated phosphates, mixed with ground coal or [charcoal](https://en.wikipedia.org/wiki/Charcoal) in an iron pot, and distilling off phosphorus vapour in a [retort](https://en.wikipedia.org/wiki/Retort).[[50]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-v-50) [Carbon monoxide](https://en.wikipedia.org/wiki/Carbon_monoxide) and other flammable gases produced during the reduction process were burnt off in a [flare stack](https://en.wikipedia.org/wiki/Gas_flare).

In the 1840s, world phosphate production turned to the mining of tropical island deposits formed from bird and bat [guano](https://en.wikipedia.org/wiki/Guano) (see also [Guano Islands Act](https://en.wikipedia.org/wiki/Guano_Islands_Act)). These became an important source of phosphates for fertiliser in the latter half of the 19th century.[[51]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-51)

**Phosphate rock**

[Phosphate rock](https://en.wikipedia.org/wiki/Phosphate_rock), which usually contains calcium phosphate, was first used in 1850 to make phosphorus, and following the introduction of the electric arc furnace by [James Burgess Readman](https://en.wikipedia.org/wiki/James_Burgess_Readman) in 1888[[52]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-52) (patented 1889),[[53]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-53) elemental phosphorus production switched from the bone-ash heating, to electric arc production from phosphate rock. After the depletion of world guano sources about the same time, mineral phosphates became the major source of phosphate fertiliser production. Phosphate rock production greatly increased after World War II, and remains the primary global source of phosphorus and phosphorus chemicals today. See the article on [peak phosphorus](https://en.wikipedia.org/wiki/Peak_phosphorus) for more information on the history and present state of phosphate mining. Phosphate rock remains a feedstock in the fertiliser industry, where it is treated with sulfuric acid to produce various "[superphosphate](https://en.wikipedia.org/wiki/Superphosphate)" fertiliser products.

**Incendiaries**

White phosphorus was first made commercially in the 19th century for the [match](https://en.wikipedia.org/wiki/Match) industry. This used bone ash for a phosphate source, as described above. The bone-ash process became obsolete when the [submerged-arc furnace for phosphorus production](https://en.wikipedia.org/wiki/Submerged-arc_furnace_for_phosphorus_production) was introduced to reduce phosphate rock.[[54]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-vii-54)[[55]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-mellor-718-720-55) The electric furnace method allowed production to increase to the point where phosphorus could be used in weapons of war.[[26]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-shockinghistory-26)[[56]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-xi-56) In [World War I](https://en.wikipedia.org/wiki/World_War_I), it was used in incendiaries, [smoke screens](https://en.wikipedia.org/wiki/Smoke_screen) and tracer bullets.[[56]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-xi-56) A special incendiary bullet was developed to shoot at [hydrogen](https://en.wikipedia.org/wiki/Hydrogen)-filled [Zeppelins](https://en.wikipedia.org/wiki/Zeppelin) over Britain (hydrogen being highly [flammable](https://en.wikipedia.org/wiki/Flammable)).[[56]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-xi-56) During [World War II](https://en.wikipedia.org/wiki/World_War_II), [Molotov cocktails](https://en.wikipedia.org/wiki/Molotov_cocktail) made of phosphorus dissolved in [petrol](https://en.wikipedia.org/wiki/Petrol) were distributed in Britain to specially selected civilians within the British resistance operation, for defence; and phosphorus incendiary bombs were used in war on a large scale. Burning phosphorus is difficult to extinguish and if it splashes onto human skin it has horrific effects.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13)

Early matches used white phosphorus in their composition, which was dangerous due to its toxicity. Murders, suicides and accidental [poisonings](https://en.wikipedia.org/wiki/Poison) resulted from its use. (An apocryphal tale tells of a woman attempting to murder her husband with white phosphorus in his food, which was detected by the stew's giving off luminous steam).[[26]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-shockinghistory-26) In addition, exposure to the vapours gave match workers a severe [necrosis](https://en.wikipedia.org/wiki/Necrosis) of the bones of the jaw, the infamous "[phossy jaw](https://en.wikipedia.org/wiki/Phossy_jaw)". When a safe process for manufacturing red phosphorus was discovered, with its far lower flammability and toxicity, laws were enacted, under the [Berne Convention (1906)](https://en.wikipedia.org/wiki/Berne_Convention_(1906)), requiring its adoption as a safer alternative for match manufacture.[[57]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-phbook-57) The toxicity of white phosphorus led to discontinuation of its use in matches.[[58]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-58) The Allies used phosphorus [incendiary bombs](https://en.wikipedia.org/wiki/Incendiary_bomb) in [World War II](https://en.wikipedia.org/wiki/World_War_II) to destroy Hamburg, the place where the "miraculous bearer of light" was first discovered.[[44]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-schmundt-44)

**Production**

Mining of phosphate rock in [Nauru](https://en.wikipedia.org/wiki/Nauru)

Most production of phosphorus-bearing material is for agriculture fertilisers. For this purpose, phosphate minerals are converted to [phosphoric acid](https://en.wikipedia.org/wiki/Phosphoric_acid). It follows two distinct chemical routes, the main one being treatment of phosphate minerals with sulfuric acid. The other process utilises white phosphorus, which may be produced by reaction and distillation from very low grade phosphate sources. The white phosphorus is then oxidised to phosphoric acid and subsequently neutralised with base to give phosphate salts. Phosphoric acid produced from white phosphorus is relatively pure and is the main route for the production of phosphates for all purposes, including detergent production.

In the early 1990s, Albright and Wilson's purified wet phosphoric acid business was being adversely affected by phosphate rock sales by China and the entry of their long-standing Moroccan phosphate suppliers into the purified wet phosphoric acid business.[[59]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-podger-287-298-59)

**Peak phosphorus**

Main article: [Peak phosphorus](https://en.wikipedia.org/wiki/Peak_phosphorus)

In 2017, the USGS estimated 68 billion tons of world reserves, where reserve figures refer to the amount assumed recoverable at current market prices; 0.261 billion tons were mined in 2016.[[60]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-60) Critical to contemporary agriculture, its annual demand is rising nearly twice as fast as the growth of the human population.[[33]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-MJ-33)

The production of phosphorus may have peaked already (as per 2011), leading to the possibility of global shortages by 2040.[[61]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-61) In 2007, at the rate of consumption, the supply of phosphorus was estimated to run out in 345 years.[[62]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-62) However, some scientists now believe that a "[peak phosphorus](https://en.wikipedia.org/wiki/Peak_phosphorus)" will occur in 30 years and that "At current rates, reserves will be depleted in the next 50 to 100 years."[[63]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-63) Cofounder of [Boston](https://en.wikipedia.org/wiki/Boston)-based investment firm and environmental foundation [Jeremy Grantham](https://en.wikipedia.org/wiki/Grantham) wrote in [*Nature*](https://en.wikipedia.org/wiki/Nature_(journal)) in November 2012 that consumption of the element "must be drastically reduced in the next 20-40 years or we will begin to starve."[[33]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-MJ-33)[[64]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-64) According to N.N. Greenwood and A. Earnshaw, authors of the textbook, *Chemistry of the Elements,* however, phosphorus comprises about 0.1% by mass of the average rock, and consequently the Earth's supply is vast, although dilute.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13)

**Elemental phosphorus**

Presently, about 1,000,000 [short tons](https://en.wikipedia.org/wiki/Short_ton) (910,000 [t](https://en.wikipedia.org/wiki/Tonne)) of elemental phosphorus is produced annually. Calcium phosphate (phosphate rock), mostly mined in Florida and North Africa, can be heated to 1,200–1,500 °C with sand, which is mostly SiO  
2, and [coke](https://en.wikipedia.org/wiki/Coke_(fuel)) (refined coal) to produce vaporised P  
4. The product is subsequently condensed into a white powder under water to prevent oxidation by air. Even under water, [white phosphorus](https://en.wikipedia.org/wiki/White_phosphorus) is slowly converted to the more stable red phosphorus [allotrope](https://en.wikipedia.org/wiki/Allotrope). The chemical equation for this process when starting with fluoroapatite, a common phosphate mineral, is:

4 Ca5(PO4)3F + 18 SiO2 + 30 C → 3 P4 + 30 CO + 18 CaSiO3 + 2 CaF2

Side products from this process include ferrophosphorus, a crude form of Fe2P, resulting from iron impurities in the mineral precursors. The silicate [slag](https://en.wikipedia.org/wiki/Slag) is a useful construction material. The fluoride is sometimes recovered for use in [water fluoridation](https://en.wikipedia.org/wiki/Water_fluoridation). More problematic is a "mud" containing significant amounts of white phosphorus. Production of white phosphorus is conducted in large facilities in part because it is energy intensive. The white phosphorus is transported in molten form. Some major accidents have occurred during transportation; train derailments at [Brownston, Nebraska](https://en.wikipedia.org/wiki/Brownstone) and [Miamisburg, Ohio](https://en.wikipedia.org/wiki/Miamisburg,_Ohio) led to large fires. The worst incident in recent times was an environmental contamination in 1968 when the sea was polluted from spillage and/or inadequately treated sewage from a white phosphorus plant at [Placentia Bay, Newfoundland](https://en.wikipedia.org/wiki/Placentia_Bay,_Newfoundland).[[65]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-65)

Another process by which elemental phosphorus is extracted includes applying at high temperatures (1500 °C):[[66]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-66)

2 Ca3(PO4)2 + 6 SiO2 + 10 C → 6 CaSiO3 + 10 CO + P4

Historically, before the development of mineral-based extractions, white phosphorus was isolated on an industrial scale from bone ash.[[67]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-67) In this process, the [tricalcium phosphate](https://en.wikipedia.org/wiki/Tricalcium_phosphate) in bone ash is converted to [monocalcium phosphate](https://en.wikipedia.org/wiki/Monocalcium_phosphate) with [sulfuric acid](https://en.wikipedia.org/wiki/Sulfuric_acid):

Ca3(PO4)2 + 2 H2SO4 → Ca(H2PO4)2 + 2 CaSO4

[Monocalcium phosphate](https://en.wikipedia.org/wiki/Monocalcium_phosphate) is then dehydrated to the corresponding metaphosphate:

Ca(H2PO4)2 → Ca(PO3)2 + 2 H2O

When ignited to a white heat with [charcoal](https://en.wikipedia.org/wiki/Charcoal), calcium metaphosphate yields two-thirds of its weight of white phosphorus while one-third of the phosphorus remains in the residue as calcium orthophosphate:

3 Ca(PO3)2 + 10 C → Ca3(PO4)2 + 10 CO + P4

**Applications**

**Fertiliser**

Main article: [Fertiliser](https://en.wikipedia.org/wiki/Fertiliser)

Phosphorus is an essential plant nutrient (often the limiting nutrient), and the bulk of all phosphorus production is in concentrated phosphoric acids for [agriculture](https://en.wikipedia.org/wiki/Agriculture) [fertiliser](https://en.wikipedia.org/wiki/Fertiliser)s, containing as much as 70% to 75% P2O5. Its annual demand is rising nearly twice as fast as the growth of the human population. That led to large increase in [phosphate](https://en.wikipedia.org/wiki/Phosphate) (PO43−) production in the second half of the 20th century.[[33]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-MJ-33) Artificial phosphate fertilisation is necessary because phosphorus is essential to all living organisms; natural phosphorus-bearing compounds are mostly insoluble and inaccessible to plants, and the natural cycle of phosphorus is very slow. Fertiliser is often in the form of superphosphate of lime, a mixture of calcium dihydrogen phosphate (Ca(H2PO4)2), and calcium sulfate dihydrate (CaSO4·2H2O) produced reacting sulfuric acid and water with calcium phosphate.

Processing phosphate minerals with sulfuric acid for obtaining fertiliser is so important to the global economy that this is the primary industrial market for [sulfuric acid](https://en.wikipedia.org/wiki/Sulfuric_acid) and the greatest industrial use of elemental [sulfur](https://en.wikipedia.org/wiki/Sulfur).[[68]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-68)

|  |  |
| --- | --- |
| **Widely used compounds** | **Use** |
| [Ca(H2PO4)2·H2O](https://en.wikipedia.org/wiki/Monocalcium_phosphate) | Baking powder and fertilisers |
| [CaHPO4·2H2O](https://en.wikipedia.org/wiki/Dicalcium_phosphate) | Animal food additive, toothpowder |
| [H3PO4](https://en.wikipedia.org/wiki/Phosphoric_acid) | Manufacture of phosphate fertilisers |
| [PCl3](https://en.wikipedia.org/wiki/Phosphorus_trichloride) | Manufacture of POCl3 and pesticides |
| [POCl3](https://en.wikipedia.org/wiki/Phosphoryl_chloride) | Manufacture of plasticiser |
| [P4S10](https://en.wikipedia.org/wiki/Phosphorus_pentasulfide) | Manufacturing of additives and pesticides |
| [Na5P3O10](https://en.wikipedia.org/wiki/Sodium_triphosphate) | Detergents |

**Organophosphorus**

White phosphorus is widely used to make [organophosphorus compounds](https://en.wikipedia.org/wiki/Organophosphorus_compound) through intermediate [phosphorus chlorides](https://en.wikipedia.org/wiki/Phosphorus_chlorides) and two phosphorus sulfides, [phosphorus pentasulfide](https://en.wikipedia.org/wiki/Phosphorus_pentasulfide) and [phosphorus sesquisulfide](https://en.wikipedia.org/wiki/Phosphorus_sesquisulfide).[[69]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-69) Organophosphorus compounds have many applications, including in [plasticisers](https://en.wikipedia.org/wiki/Plasticizer), [flame retardants](https://en.wikipedia.org/wiki/Flame_retardant), [pesticides](https://en.wikipedia.org/wiki/Pesticide), extraction agents, nerve agents and [water treatment](https://en.wikipedia.org/wiki/Water_treatment).[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13)[[70]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-70)

**Metallurgical aspects**

Phosphorus is also an important component in [steel](https://en.wikipedia.org/wiki/Steel) production, in the making of [phosphor bronze](https://en.wikipedia.org/wiki/Phosphor_bronze), and in many other related products.[[71]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-71)[[72]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-72) Phosphorus is added to metallic copper during its smelting process to react with oxygen present as an impurity in copper and to produce phosphorus-containing copper ([CuOFP](https://en.wikipedia.org/wiki/CuOFP)) alloys with a higher [hydrogen embrittlement](https://en.wikipedia.org/wiki/Hydrogen_embrittlement) resistance than normal copper.[[73]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-73)

**Matches**

[](https://en.wikipedia.org/wiki/File:Match_striking_surface.jpg)

Match striking surface made of a mixture of red phosphorus, glue and ground glass. The glass powder is used to increase the friction.

Main article: [Match](https://en.wikipedia.org/wiki/Match)

The first striking match with a phosphorus head was invented by [Charles Sauria](https://en.wikipedia.org/wiki/Charles_Sauria) in 1830. These matches (and subsequent modifications) were made with heads of white phosphorus, an oxygen-releasing compound ([potassium chlorate](https://en.wikipedia.org/wiki/Potassium_chlorate), [lead dioxide](https://en.wikipedia.org/wiki/Lead_dioxide), or sometimes [nitrate](https://en.wikipedia.org/wiki/Nitrate)), and a binder. They were poisonous to the workers in manufacture,[[74]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-74) sensitive to storage conditions, toxic if ingested, and hazardous when accidentally ignited on a rough surface.[[75]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-crass9-75)[[76]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-76) Production in several countries was banned between 1872 and 1925.[[77]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-77) The international [Berne Convention](https://en.wikipedia.org/wiki/Berne_Convention_(1906)), ratified in 1906, prohibited the use of white phosphorus in matches.

In consequence, the 'strike-anywhere' matches were gradually replaced by 'safety matches', wherein the white phosphorus was replaced by [phosphorus sesquisulfide](https://en.wikipedia.org/wiki/Phosphorus_sesquisulfide) (P4S3), sulfur, or antimony sulfide. Such matches are difficult to ignite on any surface other than a special strip. The strip contains red phosphorus that heats up upon striking, reacts with the oxygen-releasing compound in the head, and ignites the flammable material of the head.[[16]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-wiberg-16)[[69]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-69)

**Water softening**

[Sodium tripolyphosphate](https://en.wikipedia.org/wiki/Sodium_tripolyphosphate) made from phosphoric acid is used in laundry detergents in some countries, but banned for this use in others.[[18]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-CRC-18) This compound softens the water to enhance the performance of the detergents and to prevent pipe/boiler tube [corrosion](https://en.wikipedia.org/wiki/Corrosion).[[78]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-78)

**Miscellaneous**

* Phosphates are used to make special glasses for [sodium lamps](https://en.wikipedia.org/wiki/Sodium_lamp).[[18]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-CRC-18)
* Bone-ash, [calcium phosphate](https://en.wikipedia.org/wiki/Calcium_phosphate), is used in the production of fine china.[[18]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-CRC-18)
* Phosphoric acid made from elemental phosphorus is used in food applications such as [soft drinks](https://en.wikipedia.org/wiki/Soft_drink#Phosphate_soda), and as a starting point for food grade phosphates.[[69]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-69) These include mono-calcium phosphate for [baking powder](https://en.wikipedia.org/wiki/Baking_powder) and [sodium tripolyphosphate](https://en.wikipedia.org/wiki/Sodium_tripolyphosphate).[[69]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-69) Phosphates are used to improve the characteristics of processed meat and cheese, and in toothpaste.[[69]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-threlfall-69)
* [White phosphorus](https://en.wikipedia.org/wiki/White_phosphorus_munitions), called "WP" (slang term "Willie Peter") is used in [military](https://en.wikipedia.org/wiki/Military) applications as [incendiary bombs](https://en.wikipedia.org/wiki/Incendiary_device), for [smoke-screening](https://en.wikipedia.org/wiki/Smoke-screen) as smoke pots and [smoke bombs](https://en.wikipedia.org/wiki/Smoke_bomb), and in [tracer ammunition](https://en.wikipedia.org/wiki/Tracer_ammunition). It is also a part of an obsolete [M34 White Phosphorus US hand grenade](https://en.wikipedia.org/wiki/M34_grenade). This multipurpose grenade was mostly used for signaling, smoke screens, and inflammation; it could also cause severe burns and had a psychological impact on the enemy.[[79]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-79)[[80]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-80) Military uses of white phosphorus are constrained by international law.
* In trace amounts, phosphorus is used as a [dopant](https://en.wikipedia.org/wiki/Dopant) for [n-type semiconductors](https://en.wikipedia.org/wiki/N-type_semiconductor).
* 32P and 33P are used as radioactive tracers in biochemical laboratories.[[81]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-81)
* Phosphate is a strong [complexing agent](https://en.wikipedia.org/wiki/Complexing_agent) for the hexavalent [uranyl](https://en.wikipedia.org/wiki/Uranyl) (UO22+) species; for this reason, [apatite](https://en.wikipedia.org/wiki/Apatite) and other natural phosphates can be very rich in [uranium](https://en.wikipedia.org/wiki/Uranium).
* [Tributylphosphate](https://en.wikipedia.org/wiki/Tributylphosphate) is an [organophosphate](https://en.wikipedia.org/wiki/Organophosphate) soluble in [kerosene](https://en.wikipedia.org/wiki/Kerosene) used to extract uranium in the [Purex](https://en.wikipedia.org/wiki/Purex) process for reprocessing [spent nuclear fuel](https://en.wikipedia.org/wiki/Spent_nuclear_fuel).

**Biological role**

Inorganic phosphorus in the form of the phosphate PO3−  
4 is required for all known forms of [life](https://en.wikipedia.org/wiki/Life).[[82]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-82) Phosphorus plays a major role in the structural framework of [DNA](https://en.wikipedia.org/wiki/DNA) and [RNA](https://en.wikipedia.org/wiki/RNA). Living cells use phosphate to transport cellular energy with [adenosine triphosphate](https://en.wikipedia.org/wiki/Adenosine_triphosphate) (ATP), necessary for every cellular process that uses energy. ATP is also important for [phosphorylation](https://en.wikipedia.org/wiki/Phosphorylation), a key regulatory event in cells. [Phospholipids](https://en.wikipedia.org/wiki/Phospholipid) are the main structural components of all cellular membranes. [Calcium phosphate](https://en.wikipedia.org/wiki/Calcium_phosphate) salts assist in stiffening [bones](https://en.wikipedia.org/wiki/Bone).[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13) Biochemists commonly use the abbreviation "Pi" to refer to inorganic phosphate.[[83]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-83)

Every living cell is encased in a membrane that separates it from its surroundings. Cellular membranes are composed of a phospholipid matrix and proteins, typically in the form of a bilayer. Phospholipids are derived from [glycerol](https://en.wikipedia.org/wiki/Glycerol) with two of the glycerol hydroxyl (OH) protons replaced by fatty acids as an [ester](https://en.wikipedia.org/wiki/Ester), and the third hydroxyl proton has been replaced with phosphate bonded to another alcohol.[[84]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-84)

An average adult human contains about 0.7 kg of phosphorus, about 85–90% in bones and teeth in the form of [apatite](https://en.wikipedia.org/wiki/Apatite), and the remainder in soft tissues and extracellular fluids (~1%). The phosphorus content increases from about 0.5 weight% in infancy to 0.65–1.1 weight% in adults. Average phosphorus concentration in the blood is about 0.4 g/L, about 70% of that is organic and 30% inorganic phosphates.[[85]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-85) An adult with healthy diet consumes and excretes about 1–3 grams of phosphorus per day, with consumption in the form of inorganic phosphate and phosphorus-containing biomolecules such as nucleic acids and phospholipids; and excretion almost exclusively in the form of phosphate ions such as H  
2PO−  
4 and HPO2−  
4. Only about 0.1% of body phosphate circulates in the blood, paralleling the amount of phosphate available to soft tissue cells.

**Bone and teeth enamel**

The main component of bone is [hydroxyapatite](https://en.wikipedia.org/wiki/Hydroxyapatite) as well as amorphous forms of calcium phosphate, possibly including carbonate. Hydroxyapatite is the main component of tooth enamel. [Water fluoridation](https://en.wikipedia.org/wiki/Water_fluoridation) enhances the resistance of teeth to decay by the partial conversion of this mineral to the still harder material called fluoroapatite:[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13)

Ca  
5(PO  
4)  
3OH + F−  
→ Ca  
5(PO  
4)  
3F + OH−

**Phosphorus deficiency**

In medicine, phosphate deficiency syndrome may be caused by [malnutrition](https://en.wikipedia.org/wiki/Malnutrition), by failure to absorb phosphate, and by metabolic syndromes that draw phosphate from the blood (such as in [refeeding syndrome](https://en.wikipedia.org/wiki/Refeeding_syndrome) after malnutrition[[86]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-pmid18583681-86)) or pass too much of it into the urine. All are characterised by [hypophosphatemia](https://en.wikipedia.org/wiki/Hypophosphatemia), which is a condition of low levels of soluble phosphate levels in the blood serum and inside the cells. Symptoms of hypophosphatemia include neurological dysfunction and disruption of muscle and blood cells due to lack of ATP. Too much phosphate can lead to diarrhoea and calcification (hardening) of organs and soft tissue, and can interfere with the body's ability to use iron, calcium, magnesium, and zinc.[[87]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-87)

Phosphorus is an essential [macromineral](https://en.wikipedia.org/wiki/Macromineral) for plants, which is studied extensively in [edaphology](https://en.wikipedia.org/wiki/Edaphology) to understand plant uptake from [soil](https://en.wikipedia.org/wiki/Soil) systems. Phosphorus is a [limiting factor](https://en.wikipedia.org/wiki/Limiting_factor) in many [ecosystems](https://en.wikipedia.org/wiki/Ecosystem); that is, the scarcity of phosphorus limits the rate of organism growth. An excess of phosphorus can also be problematic, especially in aquatic systems where [eutrophication](https://en.wikipedia.org/wiki/Eutrophication) sometimes leads to [algal blooms](https://en.wikipedia.org/wiki/Algal_blooms).[[33]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-MJ-33)

**Dietary recommendations**

The U.S. Institute of Medicine (IOM) updated Estimated Average Requirements (EARs) and Recommended Dietary Allowances (RDAs) for phosphorus in 1997. If there is not sufficient information to establish EARs and RDAs, an estimate designated [Adequate Intake](https://en.wikipedia.org/wiki/Adequate_Intake) (AI) is used instead. The current EAR for phosphorus for people ages 19 and up is 580 mg/day. The RDA is 700 mg/day. RDAs are higher than EARs so as to identify amounts that will cover people with higher than average requirements. RDA for pregnancy and lactation are also 700 mg/day. For children ages 1–18 years the RDA increases with age from 460 to 1250 mg/day. As for safety, the IOM sets [Tolerable upper intake levels](https://en.wikipedia.org/wiki/Tolerable_upper_intake_level) (ULs) for vitamins and minerals when evidence is sufficient. In the case of phosphorus the UL is 4000 mg/day. Collectively the EARs, RDAs, AIs and ULs are referred to as [Dietary Reference Intakes](https://en.wikipedia.org/wiki/Dietary_Reference_Intake) (DRIs).[[88]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-DRItext-88)

The [European Food Safety Authority](https://en.wikipedia.org/wiki/European_Food_Safety_Authority) (EFSA) refers to the collective set of information as Dietary Reference Values, with Population Reference Intake (PRI) instead of RDA, and Average Requirement instead of EAR. AI and UL defined the same as in United States. For people ages 15 and older, including pregnancy and lactation, the AI is set at 550 mg/day. For children ages 4–10 years the AI is 440 mg/day, for ages 11–17 640 mg/day. These AIs are lower than the U.S RDAs. In both systems, teenagers need more than adults.[[89]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-89) The European Food Safety Authority reviewed the same safety question and decided that there was not sufficient information to set a UL.[[90]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-90)

For U.S. food and dietary supplement labeling purposes the amount in a serving is expressed as a percent of Daily Value (%DV). For phosphorus labeling purposes 100% of the Daily Value was 1000 mg, but as of May 27, 2016 it was revised to 1250 mg to bring it into agreement with the RDA.[[91]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-FedReg-91) A table of the old and new adult Daily Values is provided at [Reference Daily Intake](https://en.wikipedia.org/wiki/Reference_Daily_Intake). The original deadline to be in compliance was July 28, 2018, but on September 29, 2017 the FDA released a proposed rule that extended the deadline to January 1, 2020 for large companies and January 1, 2021 for small companies.[[92]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-FDAdelay-92)

**Food sources**

The main food sources for phosphorus are the same as those containing protein, although proteins do not contain phosphorus. For example, milk, meat, and soya typically also have phosphorus. As a rule, if a diet has sufficient protein and calcium, the amount of phosphorus is probably sufficient.[[93]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-93)

**Precautions**

[](https://en.wikipedia.org/wiki/File:Phosphorus_explosion.gif)

Phosphorus explosion

Organic compounds of phosphorus form a wide class of materials; many are required for life, but some are extremely toxic. Fluorophosphate [esters](https://en.wikipedia.org/wiki/Ester) are among the most potent [neurotoxins](https://en.wikipedia.org/wiki/Neurotoxin) known. A wide range of organophosphorus compounds are used for their toxicity as [pesticides](https://en.wikipedia.org/wiki/Pesticides) ([herbicides](https://en.wikipedia.org/wiki/Herbicides), [insecticides](https://en.wikipedia.org/wiki/Insecticides), [fungicides](https://en.wikipedia.org/wiki/Fungicides), etc.) and [weaponised](https://en.wikipedia.org/wiki/Weapon) as nerve agents against enemy humans. Most inorganic phosphates are relatively nontoxic and essential nutrients.[[13]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-Greenwood-13)

The white phosphorus allotrope presents a significant hazard because it ignites in air and produces phosphoric acid residue. Chronic white phosphorus poisoning leads to necrosis of the jaw called "[phossy jaw](https://en.wikipedia.org/wiki/Phossy_jaw)". White phosphorus is [toxic](https://en.wikipedia.org/wiki/Toxicity), causing severe liver damage on ingestion and may cause a condition known as "Smoking Stool Syndrome".[[94]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-94)

In the past, external exposure to elemental phosphorus was treated by washing the affected area with 2% [copper sulfate](https://en.wikipedia.org/wiki/Copper_sulfate) solution to form harmless compounds that are then washed away. According to the recent *US Navy's Treatment of Chemical Agent Casualties and Conventional Military Chemical Injuries: FM8-285: Part 2 Conventional Military Chemical Injuries*, "Cupric (copper(II)) sulfate has been used by U.S. personnel in the past and is still being used by some nations. However, copper sulfate is toxic and its use will be discontinued. Copper sulfate may produce kidney and cerebral toxicity as well as intravascular hemolysis."[[95]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-95)

The manual suggests instead "*a bicarbonate solution to neutralise phosphoric acid, which will then allow removal of visible white phosphorus. Particles often can be located by their emission of smoke when air strikes them, or by their phosphorescence in the dark. In dark surroundings, fragments are seen as luminescent spots. Promptly* [*debride*](https://en.wikipedia.org/wiki/Debridement) *the burn if the patient's condition will permit removal of bits of WP (white phosphorus) that might be absorbed later and possibly produce systemic poisoning. DO NOT apply oily-based* [*ointments*](https://en.wikipedia.org/wiki/Topical#Ointment) *until it is certain that all WP has been removed. Following complete removal of the particles, treat the lesions as thermal burns.*"[[note 1]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-96)[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] As white phosphorus readily mixes with oils, any oily substances or ointments are not recommended until the area is thoroughly cleaned and all white phosphorus removed.

People can be exposed to phosphorus in the workplace by inhalation, ingestion, skin contact, and eye contact. The [Occupational Safety and Health Administration](https://en.wikipedia.org/wiki/Occupational_Safety_and_Health_Administration) (OSHA) has set the phosphorus exposure limit ([Permissible exposure limit](https://en.wikipedia.org/wiki/Permissible_exposure_limit)) in the workplace at 0.1 mg/m3 over an 8-hour workday. The [National Institute for Occupational Safety and Health](https://en.wikipedia.org/wiki/National_Institute_for_Occupational_Safety_and_Health) (NIOSH) has set a [Recommended exposure limit](https://en.wikipedia.org/wiki/Recommended_exposure_limit) (REL) of 0.1 mg/m3 over an 8-hour workday. At levels of 5 mg/m3, phosphorus is [immediately dangerous to life and health](https://en.wikipedia.org/wiki/IDLH).[[96]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-97)

**US DEA List I status**

Phosphorus can reduce elemental [iodine](https://en.wikipedia.org/wiki/Iodine) to [hydroiodic acid](https://en.wikipedia.org/wiki/Hydroiodic_acid), which is a reagent effective for reducing [ephedrine](https://en.wikipedia.org/wiki/Ephedrine) or [pseudoephedrine](https://en.wikipedia.org/wiki/Pseudoephedrine) to methamphetamine.[[97]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-98) For this reason, red and white phosphorus were designated by the United States [Drug Enforcement Administration](https://en.wikipedia.org/wiki/Drug_Enforcement_Administration) as [List I precursor chemicals](https://en.wikipedia.org/wiki/DEA_list_of_chemicals) under [21 CFR 1310.02](https://en.wikipedia.org/wiki/Code_of_Federal_Regulations) effective on November 17, 2001.[[98]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-66_CFR_52670-99) In the United States, handlers of red or white phosphorus are subject to stringent regulatory controls.[[98]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-66_CFR_52670-99)[[99]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-21_CFR_1309-100)[[100]](https://en.wikipedia.org/wiki/Phosphorus#cite_note-CSA-101)

**Notes**

1. WP, (white phosphorus), exhibits chemoluminescence upon exposure to air and if there is any WP in the wound, covered by tissue or fluids such as blood serum, it will not glow until it is exposed to air, which requires a very dark room and dark-adapted eyes to see clearly

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  *Weast, Robert (1984). CRC, Handbook of Chemistry and Physics. Boca Raton, Florida: Chemical Rubber Company Publishing. pp. E110.* [*ISBN*](https://en.wikipedia.org/wiki/International_Standard_Book_Number)[*0-8493-0464-4*](https://en.wikipedia.org/wiki/Special:BookSources/0-8493-0464-4)*.*

  cf. "[Memoir on Combustion in General](http://web.lemoyne.edu/~giunta/Lavoisier1.html)" *Mémoires de l'Académie Royale des Sciences* 1777, 592–600. from Henry Marshall Leicester and Herbert S. Klickstein, *A Source Book in Chemistry 1400–1900* (New York: McGraw Hill, 1952)

  *Ellis, Bobby D.; MacDonald, Charles L. B. (2006). "Phosphorus(I) Iodide: A Versatile Metathesis Reagent for the Synthesis of Low Oxidation State Phosphorus Compounds". Inorganic Chemistry.* ***45*** *(17): 6864–74.* [*doi*](https://en.wikipedia.org/wiki/Digital_object_identifier)*:*[*10.1021/ic060186o*](https://doi.org/10.1021%2Fic060186o)*.* [*PMID*](https://en.wikipedia.org/wiki/PubMed_Identifier)[*16903744*](https://www.ncbi.nlm.nih.gov/pubmed/16903744)*.*

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