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**Ruthenium**

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| --- | --- |
| Ruthenium,  44Ru | |
| [Ruthenium a half bar.jpg](https://en.wikipedia.org/wiki/File:Ruthenium_a_half_bar.jpg) | |
| **General properties** | |
| **Pronunciation** | [/ruːˈθiːniəm/](https://en.wikipedia.org/wiki/Help:IPA/English) ​([*roo-THEE-nee-əm*](https://en.wikipedia.org/wiki/Help:Pronunciation_respelling_key)) |
| **Appearance** | silvery white metallic |
| [**Standard atomic weight**](https://en.wikipedia.org/wiki/Standard_atomic_weight) **(*A*r, standard)** | 101.07(2)[[1]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-CIAAW2016-1) |
| **Ruthenium 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](https://en.wikipedia.org/wiki/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 | [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) | | [Fe](https://en.wikipedia.org/wiki/Iron) ↑ **Ru** ↓ [Os](https://en.wikipedia.org/wiki/Osmium) | | [technetium](https://en.wikipedia.org/wiki/Technetium) ← **ruthenium** → [rhodium](https://en.wikipedia.org/wiki/Rhodium) | | | | |
| [**Atomic number**](https://en.wikipedia.org/wiki/Atomic_number)(*Z*) | 44 |
| [**Group**](https://en.wikipedia.org/wiki/Group_(periodic_table)) | [group 8](https://en.wikipedia.org/wiki/Group_8_element) |
| [**Period**](https://en.wikipedia.org/wiki/Period_(periodic_table)) | [period 5](https://en.wikipedia.org/wiki/Period_(periodic_table)#Period_5) |
| [**Block**](https://en.wikipedia.org/wiki/Block_(periodic_table)) | [d-block](https://en.wikipedia.org/wiki/D-block) |
| [**Element category**](https://en.wikipedia.org/wiki/Names_for_sets_of_chemical_elements#Category) | [transition metal](https://en.wikipedia.org/wiki/Transition_metal) |
| [**Electron configuration**](https://en.wikipedia.org/wiki/Electron_configuration) | [[Kr](https://en.wikipedia.org/wiki/Krypton)] 4d7 5s1 |
| Electrons per shell | 2, 8, 18, 15, 1 |
| **Physical properties** | |
| [**Melting point**](https://en.wikipedia.org/wiki/Melting_point) | 2607 [K](https://en.wikipedia.org/wiki/Kelvin) ​(2334 °C, ​4233 °F) |
| [**Boiling point**](https://en.wikipedia.org/wiki/Boiling_point) | 4423 K ​(4150 °C, ​7502 °F) |
| [**Density**](https://en.wikipedia.org/wiki/Density)(near r.t.) | 12.45 g/cm3 |
| when liquid (at m.p.) | 10.65 g/cm3 |
| [**Heat of fusion**](https://en.wikipedia.org/wiki/Enthalpy_of_fusion) | 38.59 [kJ/mol](https://en.wikipedia.org/wiki/Kilojoule_per_mole) |
| [**Heat of vaporization**](https://en.wikipedia.org/wiki/Enthalpy_of_vaporization) | 619 kJ/mol |
| [**Molar heat capacity**](https://en.wikipedia.org/wiki/Molar_heat_capacity) | 24.06 J/(mol·K) |
| [**Vapor pressure**](https://en.wikipedia.org/wiki/Vapor_pressure)   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | ***P***(Pa) | **1** | **10** | **100** | **1 k** | **10 k** | **100 k** | | **at *T***(K) | 2588 | 2811 | 3087 | 3424 | 3845 | 4388 | | |
| **Atomic properties** | |
| [**Oxidation states**](https://en.wikipedia.org/wiki/Oxidation_state) | −4, −2, +1,[[2]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-2) +2, **+3**, **+4**, +5, +6, +7, +8 (a mildly [acidic](https://en.wikipedia.org/wiki/Acidic) oxide) |
| [**Electronegativity**](https://en.wikipedia.org/wiki/Electronegativity) | Pauling scale: 2.2 |
| [**Ionization energies**](https://en.wikipedia.org/wiki/Ionization_energy) | * 1st: 710.2 kJ/mol * 2nd: 1620 kJ/mol * 3rd: 2747 kJ/mol |
| [**Atomic radius**](https://en.wikipedia.org/wiki/Atomic_radius) | empirical: 134 [pm](https://en.wikipedia.org/wiki/Picometre) |
| [**Covalent radius**](https://en.wikipedia.org/wiki/Covalent_radius) | 146±7 pm |
| [Color lines in a spectral range](https://en.wikipedia.org/wiki/File:Ruthenium_spectrum_visible.png)  [**Spectral lines**](https://en.wikipedia.org/wiki/Spectral_line) **of ruthenium** | |
| **Other properties** | |
| [**Crystal structure**](https://en.wikipedia.org/wiki/Crystal_structure) | ​[hexagonal close-packed](https://en.wikipedia.org/wiki/Close-packing_of_equal_spheres) (hcp)  [Hexagonal close packed crystal structure for ruthenium](https://en.wikipedia.org/wiki/File:Hexagonal_close_packed.svg) |
| [**Speed of sound**](https://en.wikipedia.org/wiki/Speed_of_sound)thin rod | 5970 m/s (at 20 °C) |
| [**Thermal expansion**](https://en.wikipedia.org/wiki/Coefficient_of_thermal_expansion) | 6.4 µm/(m·K) (at 25 °C) |
| [**Thermal conductivity**](https://en.wikipedia.org/wiki/Thermal_conductivity) | 117 W/(m·K) |
| [**Electrical resistivity**](https://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity) | 71 nΩ·m (at 0 °C) |
| [**Magnetic ordering**](https://en.wikipedia.org/wiki/Magnetism) | [paramagnetic](https://en.wikipedia.org/wiki/Paramagnetic)[[3]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-3) |
| [**Magnetic susceptibility**](https://en.wikipedia.org/wiki/Magnetic_susceptibility) | +43.2·10−6 cm3/mol (298 K)[[4]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-4) |
| [**Young's modulus**](https://en.wikipedia.org/wiki/Young%27s_modulus) | 447 GPa |
| [**Shear modulus**](https://en.wikipedia.org/wiki/Shear_modulus) | 173 GPa |
| [**Bulk modulus**](https://en.wikipedia.org/wiki/Bulk_modulus) | 220 GPa |
| [**Poisson ratio**](https://en.wikipedia.org/wiki/Poisson%27s_ratio) | 0.30 |
| [**Mohs hardness**](https://en.wikipedia.org/wiki/Mohs_scale_of_mineral_hardness) | 6.5 |
| [**Brinell hardness**](https://en.wikipedia.org/wiki/Brinell_hardness_test) | 2160 MPa |
| [**CAS Number**](https://en.wikipedia.org/wiki/CAS_Registry_Number) | 7440-18-8 |
| **History** | |
| **Naming** | after [*Ruthenia*](https://en.wikipedia.org/wiki/Ruthenia) (Latin for: medieval [Kyivska Rus'](https://en.wikipedia.org/wiki/Kievan_Rus%27) region) |
| [**Discovery**](https://en.wikipedia.org/wiki/Timeline_of_chemical_element_discoveries) **and first isolation** | [Karl Ernst Claus](https://en.wikipedia.org/wiki/Karl_Ernst_Claus) (1844) |
| **Main** [**isotopes of ruthenium**](https://en.wikipedia.org/wiki/Isotopes_of_ruthenium) | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | [**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) | | **96Ru** | 5.54% | [stable](https://en.wikipedia.org/wiki/Stable_isotope) | | | | **97Ru** | [syn](https://en.wikipedia.org/wiki/Synthetic_radioisotope) | 2.9 d | [ε](https://en.wikipedia.org/wiki/Electron_capture) | [97Tc](https://en.wikipedia.org/wiki/Technetium-97) | | [γ](https://en.wikipedia.org/wiki/Gamma_radiation) | – | | **98Ru** | 1.87% | stable | | | | **99Ru** | 12.76% | stable | | | | **100Ru** | 12.60% | stable | | | | **101Ru** | 17.06% | stable | | | | **102Ru** | 31.55% | stable | | | | **103Ru** | syn | 39.26 d | [β−](https://en.wikipedia.org/wiki/Beta_decay) | [103Rh](https://en.wikipedia.org/wiki/Rhodium-103) | | γ | – | | **104Ru** | 18.62% | stable | | | | **106Ru** | syn | 373.59 d | β− | [106Rh](https://en.wikipedia.org/wiki/Rhodium-106) | | |
| * [view](https://en.wikipedia.org/wiki/Template:Infobox_ruthenium) * [talk](https://en.wikipedia.org/wiki/Template_talk:Infobox_ruthenium) * [edit](https://en.wikipedia.org/w/index.php?title=Template:Infobox_ruthenium&action=edit)   | [references](https://en.wikipedia.org/wiki/List_of_data_references_for_chemical_elements) | |

**Ruthenium** is a [chemical element](https://en.wikipedia.org/wiki/Chemical_element) with symbol **Ru** and [atomic number](https://en.wikipedia.org/wiki/Atomic_number) 44. It is a rare [transition metal](https://en.wikipedia.org/wiki/Transition_metal) belonging to the [platinum group](https://en.wikipedia.org/wiki/Platinum_group) of the [periodic table](https://en.wikipedia.org/wiki/Periodic_table). Like the other metals of the platinum group, ruthenium is inert to most other chemicals. Russian-born scientist of Baltic-German ancestry [Karl Ernst Claus](https://en.wikipedia.org/wiki/Karl_Ernst_Claus) discovered the element in 1844 at [Kazan State University](https://en.wikipedia.org/wiki/Kazan_State_University) and named it after the Latin name of his homeland, [*Ruthenia*](https://en.wikipedia.org/wiki/Ruthenia). Ruthenium is usually found as a minor component of [platinum](https://en.wikipedia.org/wiki/Platinum) ores; the annual production has risen from about 19 [tonnes](https://en.wikipedia.org/wiki/Tonne) in 2009 [[6]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-JMM-6) to some 35.5 tonnes in 2017.[[7]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-7) Most ruthenium produced is used in wear-resistant electrical contacts and thick-film resistors. A minor application for ruthenium is in platinum [alloys](https://en.wikipedia.org/wiki/Alloy) and as a chemistry [catalyst](https://en.wikipedia.org/wiki/Catalysis). A new application of ruthenium is as the capping layer for extreme ultraviolet photomasks. Ruthenium is generally found in ores with the other platinum group metals in the [Ural Mountains](https://en.wikipedia.org/wiki/Ural_Mountains) and in [North](https://en.wikipedia.org/wiki/North_America) and [South America](https://en.wikipedia.org/wiki/South_America). Small but commercially important quantities are also found in [pentlandite](https://en.wikipedia.org/wiki/Pentlandite) extracted from [Sudbury, Ontario](https://en.wikipedia.org/wiki/Sudbury,_Ontario) and in [pyroxenite](https://en.wikipedia.org/wiki/Pyroxenite) deposits in [South Africa](https://en.wikipedia.org/wiki/South_Africa).[[8]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Platinum-Geological_Survey-8)



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  + [1.1 Physical properties](https://en.wikipedia.org/wiki/Ruthenium#Physical_properties)
  + [1.2 Isotopes](https://en.wikipedia.org/wiki/Ruthenium#Isotopes)
  + [1.3 Occurrence](https://en.wikipedia.org/wiki/Ruthenium#Occurrence)
* [2 Production](https://en.wikipedia.org/wiki/Ruthenium#Production)
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  + [5.1 Catalysis](https://en.wikipedia.org/wiki/Ruthenium#Catalysis)
    - [5.1.1 Homogeneous catalysis](https://en.wikipedia.org/wiki/Ruthenium#Homogeneous_catalysis)
    - [5.1.2 Heterogeneous catalysis](https://en.wikipedia.org/wiki/Ruthenium#Heterogeneous_catalysis)
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* [6 References](https://en.wikipedia.org/wiki/Ruthenium#References)
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**Characteristics**

**Physical properties**

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

Gas phase grown crystals of ruthenium metal.

A [polyvalent](https://en.wikipedia.org/wiki/Valence_(chemistry)#Common_valences) hard white metal. Ruthenium is a member of the [platinum group](https://en.wikipedia.org/wiki/Platinum_group) and is in [group 8](https://en.wikipedia.org/wiki/Group_8_element) of the periodic table:

|  |  |  |
| --- | --- | --- |
| [**Z**](https://en.wikipedia.org/wiki/Atomic_number) | [**Element**](https://en.wikipedia.org/wiki/Chemical_element) | [**No. of electrons/shell**](https://en.wikipedia.org/wiki/Electron_shell) |
| 26 | [iron](https://en.wikipedia.org/wiki/Iron) | 2, 8, 14, 2 |
| 44 | ruthenium | 2, 8, 18, 15, 1 |
| 76 | [osmium](https://en.wikipedia.org/wiki/Osmium) | 2, 8, 18, 32, 14, 2 |
| 108 | [hassium](https://en.wikipedia.org/wiki/Hassium) | 2, 8, 18, 32, 32, 14, 2 |

Whereas all other group 8 elements have 2 electrons in the outermost shell, in ruthenium, the outermost shell has only one electron (the final electron is in a lower shell). This anomaly is observed in the neighboring metals [niobium](https://en.wikipedia.org/wiki/Niobium) (41), [molybdenum](https://en.wikipedia.org/wiki/Molybdenum) (42), and [rhodium](https://en.wikipedia.org/wiki/Rhodium) (45).

Ruthenium has four crystal modifications and does not tarnish unless subject to high temperatures. Ruthenium dissolves in fused alkalis to give ruthenates (RuO2−  
4), is not attacked by acids (even [aqua regia](https://en.wikipedia.org/wiki/Aqua_regia)) but is attacked by [halogens](https://en.wikipedia.org/wiki/Halogen) at high temperatures.[[9]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-crc-9) Indeed, ruthenium is most readily attacked by oxidizing agents.[[10]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1076-10) Small amounts of ruthenium can increase the hardness of [platinum](https://en.wikipedia.org/wiki/Platinum) and [palladium](https://en.wikipedia.org/wiki/Palladium). The [corrosion](https://en.wikipedia.org/wiki/Corrosion) resistance of [titanium](https://en.wikipedia.org/wiki/Titanium) is increased markedly by the addition of a small amount of ruthenium.[[9]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-crc-9) The metal can be plated by [electroplating](https://en.wikipedia.org/wiki/Electroplating) and by thermal decomposition. A ruthenium-[molybdenum](https://en.wikipedia.org/wiki/Molybdenum) alloy is known to be [superconductive](https://en.wikipedia.org/wiki/Superconductivity) at temperatures below 10.6 [K](https://en.wikipedia.org/wiki/Kelvin).[[9]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-crc-9) Ruthenium is the last of the 4d transition metals that can assume the group oxidation state +8, and even then it is less stable there than the heavier congener osmium: this is the first group from the left of the table where the second and third-row transition metals display notable differences in chemical behavior. Like iron but unlike osmium, ruthenium can form aqueous cations in its lower oxidation states of +2 and +3.[[11]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1078-11)

Ruthenium is the first in a downward trend in the melting and boiling points and atomization enthalpy in the 4d transition metals after the maximum seen at [molybdenum](https://en.wikipedia.org/wiki/Molybdenum), because the 4d subshell is more than half full and the electrons are contributing less to metallic bonding. ([Technetium](https://en.wikipedia.org/wiki/Technetium), the previous element, has an exceptionally low value that is off the trend due to its half-filled [Kr]4d55s2 configuration, though the small amount of energy needed to excite it to a [Kr]4d65s1 configuration indicates that it is not as far off the trend in the 4d series as [manganese](https://en.wikipedia.org/wiki/Manganese) in the 3d transition series.)[[12]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1075-12) Unlike the lighter congener iron, ruthenium is [paramagnetic](https://en.wikipedia.org/wiki/Paramagnetic) at room temperature, as iron also is above its [Curie point](https://en.wikipedia.org/wiki/Curie_point).[[13]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1074-13)

The reduction potentials in acidic aqueous solution for some common ruthenium ions are shown below:[[14]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1077-14)

|  |  |  |
| --- | --- | --- |
| 0.455 V | Ru2+ + 2e− | ↔ Ru |
| 0.249 V | Ru3+ + e− | ↔ Ru2+ |
| 1.120 V | RuO2 + 4H+ + 2e− | ↔ Ru2+ + 2H2O |
| 1.563 V | RuO2− 4 + 8H+ + 4e− | ↔ Ru2+ + 4H2O |
| 1.368 V | RuO− 4 + 8H+ + 5e− | ↔ Ru2+ + 4H2O |
| 1.387 V | RuO4 + 4H+ + 4e− | ↔ RuO2 + 2H2O |

**Isotopes**

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

Naturally occurring ruthenium is composed of seven stable [isotopes](https://en.wikipedia.org/wiki/Isotope). Additionally, 34 [radioactive isotopes](https://en.wikipedia.org/wiki/Radioactive_isotopes) have been discovered. Of these [radioisotopes](https://en.wikipedia.org/wiki/Radioisotope), the most stable are 106Ru with a [half-life](https://en.wikipedia.org/wiki/Half-life) of 373.59 days, 103Ru with a half-life of 39.26 days and 97Ru with a half-life of 2.9 days.[[15]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-n1-15)[[16]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-n2-16)

Fifteen other radioisotopes have been characterized with [atomic weights](https://en.wikipedia.org/wiki/Atomic_weight) ranging from 89.93 [u](https://en.wikipedia.org/wiki/Unified_atomic_mass_unit) (90Ru) to 114.928 u (115Ru). Most of these have half-lives that are less than five minutes except 95Ru (half-life: 1.643 hours) and 105Ru (half-life: 4.44 hours).[[15]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-n1-15)[[16]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-n2-16)

The primary [decay mode](https://en.wikipedia.org/wiki/Decay_mode) before the most abundant isotope, 102Ru, is [electron capture](https://en.wikipedia.org/wiki/Electron_capture) and the primary mode after is [beta emission](https://en.wikipedia.org/wiki/Beta_emission). The primary [decay product](https://en.wikipedia.org/wiki/Decay_product) before 102Ru is [technetium](https://en.wikipedia.org/wiki/Technetium) and the primary decay product after is [rhodium](https://en.wikipedia.org/wiki/Rhodium).[[15]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-n1-15)[[16]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-n2-16)

**Occurrence**

See also: [category:Ruthenium minerals](https://en.wikipedia.org/wiki/Category:Ruthenium_minerals)

As the 74th [most abundant element in Earth's crust](https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust), ruthenium is relatively rare,[[17]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Emsley-17) found in about 100 [parts per trillion](https://en.wikipedia.org/wiki/Parts_per_trillion).[[18]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1071-18) This element is generally found in ores with the other platinum group metals in the [Ural Mountains](https://en.wikipedia.org/wiki/Ural_Mountains) and in North and South America. Small but commercially important quantities are also found in [pentlandite](https://en.wikipedia.org/wiki/Pentlandite) extracted from [Sudbury](https://en.wikipedia.org/wiki/Greater_Sudbury), [Ontario](https://en.wikipedia.org/wiki/Ontario), [Canada](https://en.wikipedia.org/wiki/Canada), and in [pyroxenite](https://en.wikipedia.org/wiki/Pyroxenite) deposits in [South Africa](https://en.wikipedia.org/wiki/South_Africa). The native form of ruthenium is a very rare mineral (Ir replaces part of Ru in its structure).[[19]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-USGS-YB-2006-19)[[20]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-USGS-CS-2008-20)

**Production**

Roughly 12 tonnes of ruthenium are mined each year with world reserves estimated at 5,000 tonnes.[[17]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Emsley-17) The composition of the mined [platinum group metal](https://en.wikipedia.org/wiki/Platinum_group_metal) (PGM) mixtures varies widely, depending on the geochemical formation. For example, the PGMs mined in South Africa contain on average 11% ruthenium while the PGMs mined in the former USSR contain only 2% (1992).[[21]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-21)[[22]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-22) Ruthenium, osmium, and iridium are considered the minor platinum group metals.[[13]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1074-13)

Ruthenium, like the other platinum group metals, is obtained commercially as a by-product from [nickel](https://en.wikipedia.org/wiki/Nickel), and [copper](https://en.wikipedia.org/wiki/Copper), and platinum metals ore processing. During [electrorefining of copper](https://en.wikipedia.org/wiki/Copper_extraction_techniques#Electrorefining) and nickel, noble metals such as silver, gold, and the platinum group metals precipitate as *anode mud*, the [feedstock](https://en.wikipedia.org/wiki/Feedstock) for the extraction.[[19]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-USGS-YB-2006-19)[[20]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-USGS-CS-2008-20) The metals are converted to ionized solutes by any of several methods, depending on the composition of the feedstock. One representative method is fusion with [sodium peroxide](https://en.wikipedia.org/wiki/Sodium_peroxide) followed by dissolution in [aqua regia](https://en.wikipedia.org/wiki/Aqua_regia), and solution in a mixture of [chlorine](https://en.wikipedia.org/wiki/Chlorine) with [hydrochloric acid](https://en.wikipedia.org/wiki/Hydrochloric_acid).[[23]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-ullmann-pt-23)[[24]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-kirk-pt-24) [Osmium](https://en.wikipedia.org/wiki/Osmium), ruthenium, [rhodium](https://en.wikipedia.org/wiki/Rhodium), and [iridium](https://en.wikipedia.org/wiki/Iridium) are insoluble in aqua regia and readily precipitate, leaving the other metals in solution. Rhodium is separated from the residue by treatment with molten sodium bisulfate. The insoluble residue, containing Ru, Os, and Ir is treated with sodium oxide, in which Ir is insoluble, producing dissolved Ru and Os salts. After oxidation to the volatile oxides, RuO  
4 is separated from OsO  
4 by precipitation of (NH4)3RuCl6 with ammonium chloride or by distillation or extraction with organic solvents of the volatile osmium tetroxide.[[25]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-25) [Hydrogen](https://en.wikipedia.org/wiki/Hydrogen) is used to reduce [ammonium](https://en.wikipedia.org/wiki/Ammonium) ruthenium chloride yielding a powder.[[26]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-cotton-26) The product is reduced using hydrogen, yielding the metal as a powder or [sponge metal](https://en.wikipedia.org/wiki/Sponge_metal) that can be treated with [powder metallurgy](https://en.wikipedia.org/wiki/Powder_metallurgy) techniques or [argon](https://en.wikipedia.org/wiki/Argon)-[arc welding](https://en.wikipedia.org/wiki/Arc_welding).[[27]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Hunt_1969_126–138-27)

**Chemical compounds**

See also: [Category:Ruthenium compounds](https://en.wikipedia.org/wiki/Category:Ruthenium_compounds)

The [oxidation states](https://en.wikipedia.org/wiki/Oxidation_state) of ruthenium range from 0 to +8, and −2. The properties of ruthenium and osmium [compounds](https://en.wikipedia.org/wiki/Chemical_compound) are often similar. The +2, +3, and +4 states are the most common. The most prevalent precursor is [ruthenium trichloride](https://en.wikipedia.org/wiki/Ruthenium_trichloride), a red solid that is poorly defined chemically but versatile synthetically.[[26]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-cotton-26)

**Oxides and chalcogenides**

Ruthenium can be [oxidized](https://en.wikipedia.org/wiki/Oxidation) to [ruthenium(IV) oxide](https://en.wikipedia.org/wiki/Ruthenium(IV)_oxide) (RuO2, oxidation state +4) which can in turn be oxidized by sodium metaperiodate to the volatile yellow tetrahedral [ruthenium tetroxide](https://en.wikipedia.org/wiki/Ruthenium_tetroxide), RuO4, an aggressive, strong oxidizing agent with structure and properties analogous to [osmium tetroxide](https://en.wikipedia.org/wiki/Osmium_tetroxide). Like osmium tetroxide, ruthenium tetroxide is a potent fixative and stain for electron microscopy of organic materials, and is mostly used to reveal the structure of polymer samples.[[28]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Brown-28) Dipotassium ruthenate (K2RuO4, +6), and potassium perruthenate (KRuO4, +7) are also known.[[29]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-29) Unlike osmium tetroxide, ruthenium tetroxide is less stable and is strong enough as an oxidising agent to oxidise dilute [hydrochloric acid](https://en.wikipedia.org/wiki/Hydrochloric_acid) and organic solvents like [ethanol](https://en.wikipedia.org/wiki/Ethanol) at room temperature, and is easily reduced to ruthenate (RuO2−  
4) in aqueous alkaline solutions; it decomposes to form the dioxide above 100 °C. Unlike iron but like osmium, ruthenium does not form oxides in its lower +2 and +3 oxidation states.[[30]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1080-30) Ruthenium forms dichalcogenides only when reacted directly with the [chalcogens](https://en.wikipedia.org/wiki/Chalcogen), which are diamagnetic semiconductors crystallizing in the [pyrite](https://en.wikipedia.org/wiki/Pyrite) structure and thus must contain ruthenium(II).[[30]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1080-30)

Like iron, ruthenium does not readily form oxoanions, and prefers to achieve high coordination numbers with hydroxide ions instead. Ruthenium tetroxide is reduced by cold dilute [potassium hydroxide](https://en.wikipedia.org/wiki/Potassium_hydroxide) to form black potassium perruthenate, KRuO4, with ruthenium in the +7 oxidation state. Potassium perruthenate can also be produced by oxidising potassium ruthenate, K2RuO4, with chlorine gas. The perruthenate ion is unstable and is reduced by water to form the orange ruthenate. Potassium ruthenate may be synthesized by reacting ruthenium metal with potassium hydroxide and [potassium nitrate](https://en.wikipedia.org/wiki/Potassium_nitrate).[[31]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1082-31)

Some mixed oxides are also known, such as MIIRuIVO3, Na3RuVO4, Na  
2RuV  
2O  
7, and MII  
2LnIII  
RuV  
O  
6.[[31]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1082-31)

**Halides and oxyhalides**

The highest known ruthenium halide is the [hexafluoride](https://en.wikipedia.org/wiki/Ruthenium_hexafluoride), a dark brown solid that melts at 54 °C. It hydrolyzes violently upon contact with water and easily disproportionates to form a mixture of lower ruthenium fluorides, releasing fluorine gas. [Ruthenium pentafluoride](https://en.wikipedia.org/wiki/Ruthenium_pentafluoride) is a tetrameric dark green solid that is also readily hydrolyzed, melting at 86.5 °C. The yellow [ruthenium tetrafluoride](https://en.wikipedia.org/w/index.php?title=Ruthenium_tetrafluoride&action=edit&redlink=1) is probably also polymeric and can be formed by reducing the pentafluoride with [iodine](https://en.wikipedia.org/wiki/Iodine). Among the binary compounds of ruthenium, these high oxidation states are known only in the oxides and fluorides.[[32]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1083-32)

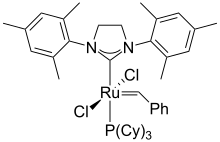
[Ruthenium trichloride](https://en.wikipedia.org/wiki/Ruthenium_trichloride) is a well-known compound, existing in a black α-form and a dark brown β-form: the trihydrate is red.[[33]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1084-33) Of the known trihalides, trifluoride is dark brown and decomposes above 650 °C, tetrabromide is dark-brown and decomposes above 400 °C, and triiodide is black.[[32]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1083-32) Of the dihalides, difluoride is not known, dichloride is brown, dibromide is black, and diiodide is blue.[[32]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1083-32) The only known oxyhalide is the pale green ruthenium(VI) oxyfluoride, RuOF4.[[33]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1084-33)

**Coordination and organometallic complexes**

Main article: [Organoruthenium chemistry](https://en.wikipedia.org/wiki/Organoruthenium_chemistry)

[](https://en.wikipedia.org/wiki/File:Tris(bipyridine)ruthenium(II)-chloride-powder.jpg)

Tris(bipyridine)ruthenium(II) chloride.

[](https://en.wikipedia.org/wiki/File:Grubbs_catalyst_Gen2.svg)

Grubbs' catalyst, which earned a Nobel Prize for its inventor, is used in [alkene metathesis](https://en.wikipedia.org/wiki/Alkene_metathesis) reactions.

Ruthenium forms a variety of coordination complexes. Examples are the many pentammine derivatives [Ru(NH3)5L]n+ that often exist for both Ru(II) and Ru(III). Derivatives of [bipyridine](https://en.wikipedia.org/wiki/Bipyridine) and [terpyridine](https://en.wikipedia.org/wiki/Terpyridine) are numerous, best known being the [luminescent](https://en.wikipedia.org/wiki/Luminescence) [tris(bipyridine)ruthenium(II) chloride](https://en.wikipedia.org/wiki/Tris(bipyridine)ruthenium(II)_chloride).

Ruthenium forms a wide range compounds with carbon-ruthenium bonds. [Grubbs' catalyst](https://en.wikipedia.org/wiki/Grubbs%27_catalyst) is used for alkene metathesis.[[34]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-34) [Ruthenocene](https://en.wikipedia.org/wiki/Ruthenocene) is analogous to ferrocene structurally, but exhibits distinctive redox properties. The colorless liquid [ruthenium pentacarbonyl](https://en.wikipedia.org/wiki/Ruthenium_pentacarbonyl) converts in the absence of CO pressure to the dark red solid [triruthenium dodecacarbonyl](https://en.wikipedia.org/wiki/Triruthenium_dodecacarbonyl). [Ruthenium trichloride](https://en.wikipedia.org/wiki/Ruthenium(III)_chloride) reacts with carbon monoxide to give many derivatives including RuHCl(CO)(PPh3)3 and Ru(CO)2(PPh3)3 ([Roper's complex](https://en.wikipedia.org/wiki/Roper%27s_complex)). Heating solutions of ruthenium trichloride in alcohols with [triphenylphosphine](https://en.wikipedia.org/wiki/Triphenylphosphine) gives [tris(triphenylphosphine)ruthenium dichloride](https://en.wikipedia.org/wiki/Tris(triphenylphosphine)ruthenium_dichloride) (RuCl2(PPh3)3), which converts to the hydride complex chlorohydridotris(triphenylphosphine)ruthenium(II) (RuHCl(PPh3)3).[[26]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-cotton-26)

**History**

Though naturally occurring platinum alloys containing all six [platinum-group metals](https://en.wikipedia.org/wiki/Platinum-group_metal) were used for a long time by [pre-Columbian](https://en.wikipedia.org/wiki/Pre-Columbian) Americans and known as a material to European chemists from the mid-16th century, not until the mid-18th century was platinum identified as a pure element. That natural platinum contained palladium, rhodium, osmium and iridium was discovered in the first decade of the 19th century.[[35]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Weeks8-35) Platinum in [alluvial sands](https://en.wikipedia.org/wiki/Alluvium) of Russian rivers gave access to raw material for use in plates and medals and for the minting of [ruble](https://en.wikipedia.org/wiki/Ruble) [coins](https://en.wikipedia.org/wiki/Coins), starting in 1828.[[36]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Roubles-36) Residues from platinum production for coinage were available in the Russian Empire, and therefore most of the research on them was done in Eastern Europe.

It is possible that the [Polish](https://en.wikipedia.org/wiki/Poland) chemist [Jędrzej Śniadecki](https://en.wikipedia.org/wiki/J%C4%99drzej_%C5%9Aniadecki) isolated element 44 (which he called "vestium" after the asteroid [Vesta](https://en.wikipedia.org/wiki/4_Vesta) discovered shortly before) from South American platinum ores in 1807. He published an announcement of his discovery in 1808.[[37]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-37) His work was never confirmed, however, and he later withdrew his claim of discovery.[[17]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Emsley-17)

[Jöns Berzelius](https://en.wikipedia.org/wiki/J%C3%B6ns_Berzelius) and [Gottfried Osann](https://en.wikipedia.org/wiki/Gottfried_Osann) nearly discovered ruthenium in 1827.[[38]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-38) They examined residues that were left after dissolving crude platinum from the [Ural Mountains](https://en.wikipedia.org/wiki/Ural_Mountains) in [aqua regia](https://en.wikipedia.org/wiki/Aqua_regia). Berzelius did not find any unusual metals, but Osann thought he found three new metals, which he called pluranium, ruthenium, and polinium. This discrepancy led to a long-standing controversy between Berzelius and Osann about the composition of the residues.[[39]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-DiscoRu-39) As Osann was not able to repeat his isolation of ruthenium, he eventually relinquished his claims.[[39]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-DiscoRu-39)[[40]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Osann2-40) The name "ruthenium" was chosen by Osann because the analysed samples stemmed from the Ural Mountains in Russia.[[41]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Osann-41) The name itself derives from [Ruthenia](https://en.wikipedia.org/wiki/Ruthenia), the Latin word for [Rus'](https://en.wikipedia.org/wiki/Rus%27_(name)), a historical area that included present-day [Ukraine](https://en.wikipedia.org/wiki/Ukraine), [Belarus](https://en.wikipedia.org/wiki/Belarus), western [Russia](https://en.wikipedia.org/wiki/Russia), and parts of [Slovakia](https://en.wikipedia.org/wiki/Slovakia) and [Poland](https://en.wikipedia.org/wiki/Poland).

In 1844, [Karl Ernst Claus](https://en.wikipedia.org/wiki/Karl_Ernst_Claus), a Russian scientist of [Baltic German](https://en.wikipedia.org/wiki/Baltic_German) descent, showed that the compounds prepared by Gottfried Osann contained small amounts of ruthenium, which Claus had [discovered](https://en.wikipedia.org/wiki/Discovery_of_the_chemical_elements) the same year.[[35]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Weeks8-35) Claus isolated ruthenium from the platinum residues of rouble production while he was working in [Kazan University](https://en.wikipedia.org/wiki/Kazan_University), [Kazan](https://en.wikipedia.org/wiki/Kazan),[[39]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-DiscoRu-39) the same way its heavier congener osmium had been discovered four decades earlier.[[18]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Greenwood1071-18) Claus showed that ruthenium oxide contained a new metal and obtained 6 grams of ruthenium from the part of crude platinum that is insoluble in [aqua regia](https://en.wikipedia.org/wiki/Aqua_regia).[[39]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-DiscoRu-39) Choosing the name for the new element, Claus stated: "I named the new body, in honour of my Motherland, ruthenium. I had every right to call it by this name because Mr. Osann relinquished his ruthenium and the word does not yet exist in chemistry."[[39]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-DiscoRu-39)[[42]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-42)

**Applications**

Because it hardens platinum and palladium alloys, ruthenium is used in [electrical contacts](https://en.wikipedia.org/wiki/Switch#Contacts), where a thin film is sufficient to achieve the desired durability. With similar properties and lower cost than rhodium,[[27]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Hunt_1969_126–138-27) electric contacts are a major use of ruthenium.[[19]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-USGS-YB-2006-19)[[43]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-43) The plate is applied to the base by electroplating[[44]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-44) or [sputtering](https://en.wikipedia.org/wiki/Sputtering).[[45]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-45)

Ruthenium dioxide with [lead](https://en.wikipedia.org/wiki/Lead) and [bismuth](https://en.wikipedia.org/wiki/Bismuth) ruthenates are used in thick-film chip resistors.[[46]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-46)[[47]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-47)[[48]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-48) These two electronic applications account for 50% of the ruthenium consumption.[[17]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-Emsley-17)

Ruthenium is seldom alloyed with metals outside the platinum group, where small quantities improve some properties. The added corrosion resistance in [titanium](https://en.wikipedia.org/wiki/Titanium) alloys led to the development of a special alloy with 0.1% ruthenium.[[49]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-49) Ruthenium is also used in some advanced high-temperature single-crystal [superalloys](https://en.wikipedia.org/wiki/Superalloys), with applications that include the turbines in [jet engines](https://en.wikipedia.org/wiki/Jet_engines). Several nickel based superalloy compositions are described, such as EPM-102 (with 3% Ru), TMS-162 (with 6% Ru), TMS-138,[[50]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-50) and TMS-174,[[51]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-51)[[52]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-52) the latter two containing 6% [rhenium](https://en.wikipedia.org/wiki/Rhenium).[[53]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-53) [Fountain pen](https://en.wikipedia.org/wiki/Fountain_pen) nibs are frequently tipped with ruthenium alloy. From 1944 onward, the famous [Parker 51](https://en.wikipedia.org/wiki/Parker_51) fountain pen was fitted with the "RU" nib, a 14K gold nib tipped with 96.2% ruthenium and 3.8% [iridium](https://en.wikipedia.org/wiki/Iridium).[[54]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-54)

Ruthenium is a component of [mixed-metal oxide](https://en.wikipedia.org/wiki/Mixed-metal_oxide) (MMO) anodes used for cathodic protection of underground and submerged structures, and for electrolytic cells for such processes as [generating chlorine](https://en.wikipedia.org/wiki/Chlorine_production) from salt water.[[55]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-55) The [fluorescence](https://en.wikipedia.org/wiki/Fluorescence) of some ruthenium complexes is quenched by oxygen, finding use in [optode](https://en.wikipedia.org/wiki/Optode) sensors for oxygen.[[56]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-56) [Ruthenium red](https://en.wikipedia.org/wiki/Ruthenium_red), [(NH3)5Ru-O-Ru(NH3)4-O-Ru(NH3)5]6+, is a [biological stain](https://en.wikipedia.org/wiki/Biological_stain) used to stain [polyanionic](https://en.wikipedia.org/wiki/Polyanion) molecules such as [pectin](https://en.wikipedia.org/wiki/Pectin) and [nucleic acids](https://en.wikipedia.org/wiki/Nucleic_acids) for [light microscopy](https://en.wikipedia.org/wiki/Light_microscopy) and [electron microscopy](https://en.wikipedia.org/wiki/Electron_microscopy).[[57]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-57) The beta-decaying isotope 106 of ruthenium is used in radiotherapy of eye tumors, mainly [malignant melanomas](https://en.wikipedia.org/wiki/Malignant_melanoma) of the [uvea](https://en.wikipedia.org/wiki/Uvea).[[58]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-58) Ruthenium-centered complexes are being researched for possible anticancer properties.[[59]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-59) Compared with platinum complexes, those of ruthenium show greater resistance to hydrolysis and more selective action on tumors.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

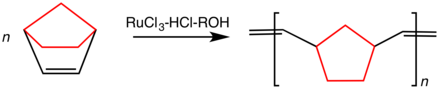
[Ruthenium tetroxide](https://en.wikipedia.org/wiki/Ruthenium_tetroxide) exposes latent fingerprints by reacting on contact with fatty oils or fats with sebaceous contaminants and producing brown/black ruthenium dioxide pigment.[[60]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-60)

**Catalysis**

Many ruthenium-containing compounds exhibit useful catalytic properties. The catalysts are conveniently divided into those that are soluble in the reaction medium, [homogeneous catalysts](https://en.wikipedia.org/wiki/Homogeneous_catalyst), and those that are not, which are called [heterogeneous catalysts](https://en.wikipedia.org/wiki/Heterogeneous_catalyst).

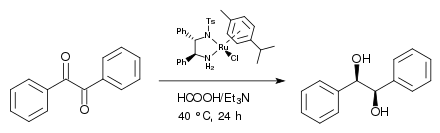
**Homogeneous catalysis**

Solutions containing [ruthenium trichloride](https://en.wikipedia.org/wiki/Ruthenium_trichloride) are highly active for [olefin metathesis](https://en.wikipedia.org/wiki/Olefin_metathesis). Such catalysts are used commercially for the production of polynorbornene for example.[[61]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-KO-61) Well defined ruthenium [carbene](https://en.wikipedia.org/wiki/Carbene) and [alkylidene](https://en.wikipedia.org/wiki/Alkylidene) complexes show comparable reactivity and provide mechanistic insights into the industrial processes.[[62]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-62) The [Grubbs' catalysts](https://en.wikipedia.org/wiki/Grubbs%27_catalyst) for example have been employed in the preparation of drugs and advanced materials.

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

RuCl3-catalyzed [ring-opening metathesis polymerization](https://en.wikipedia.org/wiki/Ring-opening_metathesis_polymerization) reaction giving polynorbornene..

Ruthenium complexes are highly active catalyst for [transfer hydrogenations](https://en.wikipedia.org/wiki/Transfer_hydrogenation) (sometimes referred to as "borrowing hydrogen" reactions). This process is employed for the [enantioselective hydrogenation](https://en.wikipedia.org/wiki/Asymmetric_hydrogenation) of [ketones](https://en.wikipedia.org/wiki/Ketone), [aldehydes](https://en.wikipedia.org/wiki/Aldehyde), and [imines](https://en.wikipedia.org/wiki/Imine). This reaction exploits using [chiral](https://en.wikipedia.org/wiki/Chiral) ruthenium complexes introduced by [Ryoji Noyori](https://en.wikipedia.org/wiki/Ryoji_Noyori).[[63]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-citation_21-63) For example, (cymene)Ru(S,S-Ts[DPEN](https://en.wikipedia.org/wiki/DPEN)) catalyzes the [hydrogenation](https://en.wikipedia.org/wiki/Hydrogenation) of [benzil](https://en.wikipedia.org/wiki/Benzil) into (*R,R*)-hydro[benzoin](https://en.wikipedia.org/wiki/Benzoin_(organic_compound)). In this reaction, [formate](https://en.wikipedia.org/wiki/Formate) and water/alcohol serve as the source of H2:[[64]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-64)[[65]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-65)

[](https://en.wikipedia.org/wiki/File:RuCl(S,S-TsDPEN)(cymene)-catalysed_R,R-hydrobenzoin_synthesis.svg)

[RuCl(*S*,*S*-TsDPEN)(cymene)]-catalysed (*R*,*R*)-hydrobenzoin synthesis (yield 100%, [ee](https://en.wikipedia.org/wiki/Enantiomeric_excess) >99%)

A [Nobel Prize in Chemistry](https://en.wikipedia.org/wiki/Nobel_Prize_in_Chemistry) was awarded in 2001 to [Ryōji Noyori](https://en.wikipedia.org/wiki/Ry%C5%8Dji_Noyori) for contributions to the field of [asymmetric hydrogenation](https://en.wikipedia.org/wiki/Asymmetric_hydrogenation).

In 2012, Masaaki Kitano (and 9 co-authors), working with an organic ruthenium catalyst, demonstrated "Ammonia Synthesis Using a Stable Electride as an Electron Donor and Reversible Hydrogen Store"[[66]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-66). Small-scale, intermittent production of ammonia, for local agricultural use, may be a viable substitute for electrical grid attachment as a sink for power generated by wind turbines in isolated rural installations.

**Heterogeneous catalysis**

Ruthenium-promoted cobalt catalysts are used in [Fischer-Tropsch synthesis](https://en.wikipedia.org/wiki/Fischer-Tropsch_synthesis).[[67]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-67)

**Emerging applications**

Some ruthenium complexes [absorb light](https://en.wikipedia.org/wiki/Absorption_(electromagnetic_radiation)) throughout the visible spectrum and are being actively researched for [solar energy](https://en.wikipedia.org/wiki/Solar_energy) technologies. For example, Ruthenium-based compounds have been used for light absorption in [dye-sensitized solar cells](https://en.wikipedia.org/wiki/Dye-sensitized_solar_cell), a promising new [low-cost solar cell](https://en.wikipedia.org/wiki/Low-cost_solar_cell) system.[[68]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-68)

Many ruthenium-based oxides show very unusual properties, such as a [quantum critical point](https://en.wikipedia.org/wiki/Quantum_critical_point) behavior,[[69]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-69) exotic [superconductivity](https://en.wikipedia.org/wiki/Superconductivity) (in its [strontium ruthenate](https://en.wikipedia.org/wiki/Strontium_ruthenate) form),[[70]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-70) and high-temperature [ferromagnetism](https://en.wikipedia.org/wiki/Ferromagnetism).[[71]](https://en.wikipedia.org/wiki/Ruthenium#cite_note-71)

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