

# Rutherfordium

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**Rutherfordium** is a chemical element with symbol **Rf** and atomic number 104, named in honor of physicist Ernest Rutherford. It is a synthetic element (an element that can be created in a laboratory but is not found in nature) and radioactive; the most stable known isotope, <sup>267</sup>Rf, has a half-life of approximately 1.3 hours.

In the periodic table of the elements, it is a d-block element and the second of the fourth-row transition elements. It is a member of the 7th period and belongs to the group 4 elements. Chemistry experiments have confirmed that rutherfordium behaves as the heavier homologue to hafnium in group 4. The chemical properties of rutherfordium are characterized only partly. They compare well with the chemistry of the other group 4 elements, even though some calculations had indicated that the element might show significantly different properties due to relativistic effects.

In the 1960s, small amounts of rutherfordium were produced in the Joint Institute for Nuclear Research in the former Soviet Union and at Lawrence Berkeley National Laboratory in California.<sup>[9]</sup> The priority of the discovery and therefore the naming of the element was disputed between Soviet and American scientists, and it was not until 1997 that International Union of Pure and Applied Chemistry (IUPAC) established rutherfordium as the official name for the element.

## Isotopes

Rutherfordium has no stable or naturally occurring isotopes. Several radioactive isotopes have been synthesized in the laboratory, either by fusing two atoms or by observing the decay of heavier elements. Sixteen different isotopes have been reported with atomic masses from 253 to 270 (with the exceptions of 264 and 269). Most of these decay predominantly through spontaneous fission pathways.<sup>[5][29]</sup>

### Rutherfordium, <sup>104</sup>Rf

General properties	
<b>Name, symbol</b>	rutherfordium, Rf
Rutherfordium in the periodic table	
<b>Atomic number</b> ( <i>Z</i> )	104
<b>Group, block</b>	group 4, d-block
<b>Period</b>	period 7
<b>Element category</b>	<span>☐</span> transition metal
<b>Standard atomic weight</b> ( <i>A</i> <sub>r</sub> )	[267]
<b>Electron configuration</b>	[Rn] 5f <sup>14</sup> 6d <sup>2</sup> 7s <sup>2</sup> <sup>[1][2]</sup>
per shell	2, 8, 18, 32, 32, 10, 2
Physical properties	
<b>Phase</b>	solid <i>(predicted)</i> <sup>[1][2]</sup>
<b>Melting point</b>	2400 K (2100 °C, 3800 °F) <i>(predicted)</i> <sup>[1][2]</sup>
<b>Boiling point</b>	5800 K (5500 °C, 9900 °F) <i>(predicted)</i> <sup>[1][2]</sup>
<b>Density</b> near r.t.	23.2 g/cm <sup>3</sup> <i>(predicted)</i> <sup>[1][2][3]</sup>
Atomic properties	
<b>Oxidation states</b>	<b>4</b> , <sup>[1]</sup> <b>(3)</b> , (2) <sup>[2][3]</sup> (parenthesized numbers are predictions)
<b>Ionization</b>	1st: 579.9 kJ/mol

## Life-times

Out of isotopes whose half-lives are known, the lighter isotopes usually have shorter half-lives; half-lives of under 50  $\mu$ s for  $^{253}\text{Rf}$  and  $^{254}\text{Rf}$  were observed.  $^{256}\text{Rf}$ ,  $^{258}\text{Rf}$ ,  $^{260}\text{Rf}$  are more stable at around 10 ms,  $^{255}\text{Rf}$ ,  $^{257}\text{Rf}$ ,  $^{259}\text{Rf}$ , and  $^{262}\text{Rf}$  live between 1 and 5 seconds, and  $^{261}\text{Rf}$ ,  $^{265}\text{Rf}$ , and  $^{263}\text{Rf}$  are more stable, at around 1, 1.5, and 10 min respectively. The heaviest isotopes are the most stable, with  $^{267}\text{Rf}$  having a measured half-life of about 1.3 h.<sup>[5]</sup> Half-lives for  $^{269}\text{Rf}$ ,  $^{271}\text{Rf}$ , and higher are not known and have not yet been predicted.

The lightest isotopes were synthesized by direct fusion between two lighter nuclei and as decay products. The heaviest isotope produced by direct fusion is  $^{262}\text{Rf}$ ; heavier isotopes have only been observed as decay products of elements with larger atomic numbers, of which only  $^{267}\text{Rf}$  has been confirmed. The heavy isotopes  $^{266}\text{Rf}$  and  $^{268}\text{Rf}$  have also been observed as electron capture daughters of the dubnium isotopes  $^{266}\text{Db}$  and  $^{268}\text{Db}$ , but have short half-lives to spontaneous fission: it seems likely that the same is true of  $^{270}\text{Rf}$ , a likely daughter of  $^{270}\text{Db}$ .<sup>[28]</sup> While the isotope  $^{264}\text{Rf}$  has yet to be observed, it is predicted to have a short half-life of 5 s.<sup>[22]</sup>

In 1999, American scientists at the University of California, Berkeley, announced that they had succeeded in synthesizing three atoms of  $^{293}\text{Og}$ .<sup>[30]</sup> These parent nuclei were reported to have successively emitted seven alpha particles to form  $^{265}\text{Rf}$  nuclei, but their claim was retracted in 2001.<sup>[31]</sup>

## Predicted properties

### Chemical

Rutherfordium is the first transactinide element and the second member of the 6d series of transition metals. Calculations on its ionization potentials, atomic radius, as well as radii, orbital energies, and ground levels of its ionized states are similar to that of hafnium and very different from that of lead. Therefore, it

<b>energies</b>	2nd: 1389.4 kJ/mol 3rd: 2296.4 kJ/mol (more) <i>(all but first estimated)</i> <sup>[2]</sup>
<b>Atomic radius</b>	empirical: 150 pm <i>(estimated)</i> <sup>[2]</sup>
<b>Covalent radius</b>	157 pm <i>(estimated)</i> <sup>[1]</sup>
<b>Miscellanea</b>	
<b>Crystal structure</b>	hexagonal close-packed (hcp) <i>(predicted)</i> <sup>[4]</sup>
<b>CAS Number</b>	53850-36-5
<b>Naming</b>	after Ernest Rutherford
<b>Discovery</b>	Joint Institute for Nuclear Research and Lawrence Berkeley National Laboratory (1964, 1969)
<b>Most stable isotopes of rutherfordium</b>	



was concluded that rutherfordium's basic properties will resemble those of other group 4 elements, below titanium, zirconium, and hafnium.<sup>[21][32]</sup> Some of its properties were determined by gas-phase experiments and aqueous chemistry. The oxidation state +4 is the only stable state for the latter two elements and therefore rutherfordium should also exhibit a stable +4 state.<sup>[32]</sup> In addition, rutherfordium is also expected to be able to form a less stable +3 state.<sup>[2]</sup> The standard reduction potential of the  $\text{Rf}^{4+}/\text{Rf}$  couple is predicted to be higher than  $-1.7\text{ V}$ .<sup>[3]</sup>

The chemical properties of rutherfordium were based on calculation which indicated that the relativistic effects on the electron shell might be strong enough that the p orbitals have a lower energy level than the d orbitals, giving it a valence electron configuration of  $6\text{d}^1\ 7\text{s}^2\ 7\text{p}^1$  or even  $7\text{s}^2\ 7\text{p}^2$ , therefore making the element behave more like lead than hafnium. With better calculation methods and studies of the chemical properties of rutherfordium compounds it could be shown that rutherfordium behaves according to the rest of the group 4 elements.<sup>[2][32]</sup>

iso	NA	half-life	DM	DE (MeV)	DP
<b>261Rf</b>	syn	70 s <sup>[5]</sup>	>80% $\alpha$	8.28	<sup>257</sup> No
			<15% $\epsilon$		<sup>261</sup> Lr
			<10% SF		
<b>263Rf</b>	syn	15 min <sup>[5]</sup>	<100% SF		
			~30% $\alpha$	7.90 ?	<sup>259</sup> No
<b>265Rf</b>	syn	$1.0^{+1.2}_{-0.3}\text{ min}^{[6][7][8]}$	SF		
<b>266Rf</b>	syn	23 s?	SF		
<b>267Rf</b>	syn	1.3 h <sup>[5]</sup>	SF		

In an analogous manner to zirconium and hafnium, rutherfordium is projected to form a very stable, refractory oxide,  $\text{RfO}_2$ . It reacts with halogens to form tetrahalides,  $\text{RfX}_4$ , which hydrolyze on contact with water to form oxyhalides  $\text{RfOX}_2$ . The tetrahalides are volatile solids existing as monomeric tetrahedral molecules in the vapor phase.<sup>[32]</sup>

In the aqueous phase, the  $\text{Rf}^{4+}$  ion hydrolyzes less than titanium(IV) and to a similar extent as zirconium and hafnium, thus resulting in the  $\text{RfO}^{2+}$  ion. Treatment of the halides with halide ions promotes the formation of complex ions. The use of chloride and bromide ions produces the hexahalide complexes  $\text{RfCl}_6^{2-}$  and  $\text{RfBr}_6^{2-}$ . For the fluoride complexes, zirconium and hafnium tend to form hepta- and octa- complexes. Thus, for the larger rutherfordium ion, the complexes  $\text{RfF}_6^{2-}$ ,  $\text{RfF}_7^{3-}$  and  $\text{RfF}_8^{4-}$  are possible.<sup>[32]</sup>

### Physical and atomic

Rutherfordium is expected to be a solid under normal conditions and assume a hexagonal close-packed crystal structure ( $c/a = 1.61$ ), similar to its lighter congener hafnium.<sup>[4]</sup> It should be a very heavy metal with a density of around  $23.2\text{ g/cm}^3$ ; in comparison, the densest known element that has had its density measured, osmium, has a density of  $22.61\text{ g/cm}^3$ . This results

from rutherfordium's high atomic weight, the lanthanide and actinide contractions, and relativistic effects, although production of enough rutherfordium to measure this quantity would be impractical, and the sample would quickly decay. The atomic radius for rutherfordium is expected to be around 150 pm. Due to the relativistic stabilization of the 7s orbital and destabilization of the 6d orbital, the  $\text{Rf}^+$  and  $\text{Rf}^{2+}$  ions are predicted to give up 6d electrons instead of 7s electrons, which is the opposite of the behavior of its lighter homologues.<sup>[2]</sup>

## Experimental chemistry

### Gas phase

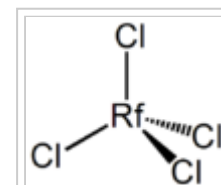
Early work on the study of the chemistry of rutherfordium focused on gas thermochromatography and measurement of relative deposition temperature adsorption curves. The initial work was carried out at Dubna in an attempt to reaffirm their discovery of the element. Recent work is more reliable regarding the identification of the parent rutherfordium radioisotopes. The isotope  $^{261\text{m}}\text{Rf}$  has been used for these studies. The experiments relied on the expectation that rutherfordium would begin the new 6d series of elements and should therefore form a volatile tetrachloride due to the tetrahedral nature of the molecule.<sup>[32][33][34]</sup> Rutherfordium(IV) chloride is more volatile than its lighter homologue hafnium(IV) chloride ( $\text{HfCl}_4$ ) because its bonds are more covalent.<sup>[2]</sup>

A series of experiments confirmed that rutherfordium behaves as a typical member of group 4, forming a tetravalent chloride ( $\text{RfCl}_4$ ) and bromide ( $\text{RfBr}_4$ ) as well as an oxychloride ( $\text{RfOCl}_2$ ). A decreased volatility was observed for  $\text{RfCl}_4$  when potassium chloride is provided as the solid phase instead of gas, highly indicative of the formation of nonvolatile  $\text{K}_2\text{RfCl}_6$  mixed salt.<sup>[21][32][35]</sup>

### Aqueous phase

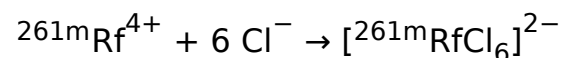
Rutherfordium is expected to have the electron configuration  $[\text{Rn}]5f^{14} 6d^2 7s^2$  and therefore behave as the heavier homologue of hafnium in group 4 of the periodic table. It should therefore readily form a hydrated  $\text{Rf}^{4+}$  ion in strong acid solution and should readily form complexes in hydrochloric acid, hydrobromic or hydrofluoric acid solutions.<sup>[32]</sup>

The most conclusive aqueous chemistry studies of rutherfordium have been performed by the Japanese team at Japan Atomic Energy Research Institute using the radioisotope  $^{261\text{m}}\text{Rf}$ . Extraction experiments from hydrochloric acid solutions using isotopes of rutherfordium, hafnium, zirconium, as well as the pseudo-group 4 element thorium have proved a non-actinide behavior for

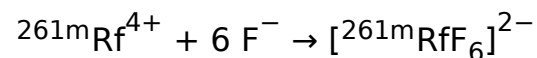


The tetrahedral structure of the  $\text{RfCl}_4$  molecule

rutherfordium. A comparison with its lighter homologues placed rutherfordium firmly in group 4 and indicated the formation of a hexachlororutherfordate complex in chloride solutions, in a manner similar to hafnium and zirconium.<sup>[32][36]</sup>



Very similar results were observed in hydrofluoric acid solutions. Differences in the extraction curves were interpreted as a weaker affinity for fluoride ion and the formation of the hexafluororutherfordate ion, whereas hafnium and zirconium ions complex seven or eight fluoride ions at the concentrations used:<sup>[32]</sup>



## Source

- Wikipedia: Rutherfordium (<https://en.wikipedia.org/wiki/Rutherfordium>)