

# Hassium

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**Hassium** is a chemical element with symbol **Hs** and atomic number 108, named after the German state of Hesse. 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>269</sup>Hs, has a half-life of approximately 9.7 seconds, although an unconfirmed metastable state, <sup>277m</sup>Hs, may have a longer half-life of about 130 seconds. More than 100 atoms of hassium have been synthesized to date.<sup>[2]</sup>

In the periodic table of the elements, it is a d-block transactinide element. It is a member of the 7th period and belongs to the group 8 elements: it is thus the sixth member of the 6d series of transition metals. Chemistry experiments have confirmed that hassium behaves as the heavier homologue to osmium in group 8. The chemical properties of hassium are characterized only partly, but they compare well with the chemistry of the other group 8 elements. In bulk quantities, hassium is expected to be a silvery metal that reacts readily with oxygen in the air, forming a volatile tetroxide.

## Isotopes

Hassium 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. Twelve different isotopes have been reported with atomic masses from 263 to 277 (with the exceptions of 272, 274, and 276), four of which, hassium-265, hassium-267, hassium-269, and hassium-277, have known metastable states (although that of hassium-277 is unconfirmed). Most of these decay predominantly through alpha decay, but some also undergo spontaneous fission.<sup>[19][30]</sup>

The lightest isotopes, which usually have shorter half-lives were synthesized by direct fusion between two lighter nuclei and as decay products. The heaviest isotope produced by direct fusion is <sup>271</sup>Hs; heavier isotopes have only been observed as decay products of elements with larger atomic numbers. In

## Hassium, <sup>108</sup>Hs

### General properties

<b>Name, symbol</b>	hassium, Hs
<b>Appearance</b>	silvery <i>(predicted)</i> <sup>[2]</sup>

### Hassium in the periodic table

<b>Atomic number</b> ( <i>Z</i> )	108
<b>Group, block</b>	group 8, 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> )	[269]
<b>Electron configuration</b>	[Rn] 5f <sup>14</sup> 6d <sup>6</sup> 7s <sup>2</sup> <sup>[3]</sup>
per shell	2, 8, 18, 32, 32, 14, 2

### Physical properties

<b>Phase</b>	solid <i>(predicted)</i> <sup>[4]</sup>
<b>Density</b> near r.t.	41 g/cm <sup>3</sup> <i>(predicted)</i> <sup>[3]</sup>

### Atomic properties

<b>Oxidation states</b>	<b>8, (6), (5), (4), (3), (2)</b> <sup>[2][3][5][6]</sup> (parenthesized oxidation states are predictions)
<b>Ionization energies</b>	1st: 733.3 kJ/mol 2nd: 1756.0 kJ/mol 3rd: 2827.0 kJ/mol (more) <i>(all but first estimated)</i> <sup>[3]</sup>

1999, American scientists at the University of California, Berkeley, announced that they had succeeded in synthesizing three atoms of  $^{293}\text{Og}$ .<sup>[34]</sup> These parent nuclei were reported to have successively emitted three alpha particles to form hassium-273 nuclei, which were claimed to have undergone an alpha decay, emitting alpha particles with decay energies of 9.78 and 9.47 MeV and half-life 1.2 s, but their claim was retracted in 2001.<sup>[35]</sup> The isotope was successfully produced in 2010 by the same team. The new data matched the previous (fabricated)<sup>[36]</sup> data.<sup>[30]</sup>

## $^{270}\text{Hs}$ : prospects for a deformed doubly magic nucleus

According to calculations, 108 is a proton magic number for deformed nuclei (nuclei that are far from spherical), and 162 is a neutron magic number for deformed nuclei. This means that such nuclei are permanently deformed in their ground state but have high, narrow fission barriers to further deformation and hence relatively long life-times to spontaneous fission.<sup>[37][38]</sup> The spontaneous fission half-lives in this region are typically reduced by a factor of  $10^9$  in comparison with those in the vicinity of the spherical doubly magic nucleus  $^{298}\text{Fl}$ , caused by the narrower fission barrier for such deformed nuclei.<sup>[39]</sup> Hence, the nucleus  $^{270}\text{Hs}$  has promise as a deformed doubly magic nucleus. Experimental data from the decay of the darmstadtium ( $Z=110$ ) isotopes  $^{271}\text{Ds}$  and  $^{273}\text{Ds}$  provides strong evidence for the magic nature of the  $N=162$  sub-shell. The recent synthesis of  $^{269}\text{Hs}$ ,  $^{270}\text{Hs}$ , and  $^{271}\text{Hs}$  also fully support the assignment of  $N=162$  as a magic number. In particular, the low decay energy for  $^{270}\text{Hs}$  is in complete agreement with calculations.<sup>[37][38][39]</sup>

Evidence for the magicity of the  $Z=108$  proton shell can be obtained from two sources: the variation in the partial spontaneous fission half-lives for isotones and the large gap in the alpha  $Q$  value for isotonic nuclei of hassium and darmstadtium.<sup>[39]</sup> For spontaneous fission, it is necessary to measure the half-lives for the isotonic nuclei  $^{268}\text{Sg}$ ,  $^{270}\text{Hs}$  and  $^{272}\text{Ds}$ .<sup>[39]</sup> Since the isotopes  $^{268}\text{Sg}$  and  $^{272}\text{Ds}$  are not currently known,<sup>[19]</sup> and fission of  $^{270}\text{Hs}$  has not been measured,<sup>[19][38]</sup> this method cannot yet be used to confirm the stabilizing nature of the  $Z=108$  shell. Good evidence for the magicity of the  $Z=108$  shell can nevertheless be found from the large differences in the alpha decay energies measured for  $^{270}\text{Hs}$ ,  $^{271}\text{Ds}$  and  $^{273}\text{Ds}$ .<sup>[37][38][39]</sup> More conclusive evidence would come from the determination of the decay energy for the unknown nucleus  $^{272}\text{Ds}$ .<sup>[39]</sup>

<b>Atomic radius</b>	empirical: 126 pm (estimated) <sup>[3]</sup>				
<b>Covalent radius</b>	134 pm (estimated) <sup>[7]</sup>				
<b>Miscellanea</b>					
<b>Crystal structure</b>	hexagonal close-packed (hcp) (predicted) <sup>[4]</sup>				
<b>CAS Number</b>	54037-57-9				
<b>Naming</b>	after <i>Hassia</i> , Latin for Hesse, Germany, where it was discovered <sup>[2]</sup>				
<b>Discovery</b>	Gesellschaft für Schwerionenforschung (1984)				
<b>Most stable isotopes of hassium</b>					
<b>iso</b>	<b>NA</b>	<b>half-life</b>	<b>DM</b>	<b>DE (MeV)</b>	<b>DP</b>
$^{277}\text{Hs}$	syn	2 s	SF		
$^{277\text{m}}\text{Hs} ?$	syn	~130 s?	SF		
$^{271}\text{Hs}$	syn	~4 s	$\alpha$	9.27, 9.13	$^{267}\text{Sg}$
$^{270}\text{Hs}$	syn	3.6 s	$\alpha$	9.02, 8.88	$^{266}\text{Sg}$
$^{269}\text{Hs}$	syn	9.7 s	$\alpha$	9.21, 9.10, 8.97	$^{265}\text{Sg}$



## Predicted properties

Various calculations show that hassium should be the heaviest known group 8 element, consistent with the periodic law. Its properties should generally match those expected for a heavier homologue of osmium, with a few deviations arising from relativistic effects.

### Physical and atomic

The previous members of group 8 have relatively high melting points (Fe, 1538 °C; Ru, 2334 °C; Os, 3033 °C). Much like them, hassium is predicted to be a solid at room temperature,<sup>[4]</sup> although the melting point of hassium has not been precisely calculated. Hassium should crystallize in the hexagonal close-packed structure ( $c/a = 1.59$ ), similarly to its lighter congener osmium.<sup>[4]</sup> Pure metallic hassium is calculated to have a bulk modulus (resistance to uniform compression) comparable to that of diamond<sup>[4][40]</sup> (442 GPa).<sup>[41]</sup> Hassium is expected to have a bulk density of 40.7 g/cm<sup>3</sup>, the highest of any of the 118 known elements and nearly twice the density of osmium,<sup>[3]</sup> the most dense measured element,<sup>[42]</sup> at 22.61 g/cm<sup>3</sup>.<sup>[43]</sup> This results from hassium's high atomic weight, the lanthanide and actinide contractions, and relativistic effects, although production of enough hassium to measure this quantity would be impractical, and the sample would quickly decay.<sup>[3]</sup> Osmium is the densest element of the first 6 periods, and its heavier congener hassium is expected to be the densest element of the first 7 periods.<sup>[3][42]</sup>

The atomic radius of hassium is expected to be around 126 pm.<sup>[3]</sup> Due to the relativistic stabilization of the 7s orbital and destabilization of the 6d orbital, the Hs<sup>+</sup> ion is predicted to have an electron configuration of [Rn] 5f<sup>14</sup> 6d<sup>5</sup> 7s<sup>2</sup>, giving up a 6d electron instead of a 7s electron, which is the opposite of the behavior of its lighter homologues. On the other hand, the Hs<sup>2+</sup> ion is expected to have an electron configuration of [Rn] 5f<sup>14</sup> 6d<sup>5</sup> 7s<sup>1</sup>, analogous to that calculated for the Os<sup>2+</sup> ion.<sup>[3]</sup>

### Chemical

Hassium is the sixth member of the 6d series of transition metals and is expected to be much like the platinum group metals.<sup>[45]</sup> 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 osmium, implying that hassium's properties would resemble those of the other group 8 elements, iron, ruthenium, and osmium.<sup>[3][46]</sup> Some of these properties were confirmed by gas-phase chemistry experiments.<sup>[27][47][48]</sup> The group 8 elements portray a wide variety of oxidation states, but ruthenium and osmium readily portray their group oxidation state of +8 (the second-highest known oxidation state for any element, which is very rare for other elements) and this state

becomes more stable as the group is descended.<sup>[44][49][50]</sup> Thus hassium is expected to form a stable +8 state.<sup>[47]</sup> Analogously to its lighter congeners, hassium is expected to also show other stable lower oxidation states, such as +6, +5, +4, +3, and +2.<sup>[2][3][6]</sup> Indeed, hassium(IV) is expected to be more stable than hassium(VIII) in aqueous solution.<sup>[3]</sup>

The group 8 elements show a very distinctive oxide chemistry which allows extrapolations to be made easily for hassium. All the lighter members have known or hypothetical tetroxides,  $\text{MO}_4$ .<sup>[51]</sup> Their oxidising power decreases as one descends the group.  $\text{FeO}_4$  is not known due to its extraordinarily large electron affinity (the amount of energy released when an electron is added to a neutral atom or molecule to form a negative ion)<sup>[52]</sup> which results in the formation of the well-known oxoanion ferrate(VI),  $\text{FeO}_4^{2-}$ .<sup>[53]</sup> Ruthenium tetroxide,  $\text{RuO}_4$ , formed by oxidation of ruthenium(VI) in acid, readily undergoes reduction to ruthenate(VI),  $\text{RuO}_4^{2-}$ .<sup>[54][55]</sup> Oxidation of ruthenium metal in air forms the dioxide,  $\text{RuO}_2$ .<sup>[56]</sup> In contrast, osmium burns to form the stable tetroxide,  $\text{OsO}_4$ ,<sup>[57][58]</sup> which complexes with the hydroxide ion to form an osmium(VIII) -ate complex,  $[\text{OsO}_4(\text{OH})_2]^{2-}$ .<sup>[59]</sup> Therefore, eka-osmium properties for hassium should be demonstrated by the formation of a stable, very volatile tetroxide  $\text{HsO}_4$ ,<sup>[2][3][27][48][49]</sup> which undergoes complexation with hydroxide to form a hassate(VIII),  $[\text{HsO}_4(\text{OH})_2]^{2-}$ .<sup>[60]</sup> Ruthenium tetroxide and osmium tetroxide are both volatile, due to their symmetrical tetrahedral molecular geometry and their being charge-neutral; hassium tetroxide should similarly be a very volatile solid. The trend of the volatilities of the group 8 tetroxides is known to be  $\text{RuO}_4 < \text{OsO}_4 > \text{HsO}_4$ , which completely confirms the calculated results. In particular, the calculated enthalpies of adsorption (the energy required for the adhesion of atoms, molecules, or ions from a gas, liquid, or dissolved solid to a surface) of  $\text{HsO}_4$ ,  $-(45.4 \pm 1) \text{ kJ}\cdot\text{mol}^{-1}$  on quartz, agrees very well with the experimental value of  $-(46 \pm 2) \text{ kJ}\cdot\text{mol}^{-1}$ .<sup>[61]</sup>

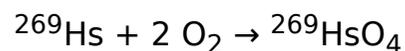
## Experimental chemistry

Despite the fact that the selection of a volatile hassium compound (hassium tetroxide) for gas-phase chemical studies was clear from the beginning,<sup>[3][49]</sup> the chemical characterization of hassium was considered a difficult task for a long time.<sup>[49]</sup> Although hassium isotopes were first synthesized in 1984, it was not until 1996 that a hassium isotope long-lived enough to allow chemical studies to be performed was synthesized. Unfortunately, this hassium isotope,  $^{269}\text{Hs}$ , was then synthesized indirectly from the decay of  $^{277}\text{Cn}$ ,<sup>[49]</sup> not only are indirect synthesis methods not favourable for chemical studies,<sup>[3]</sup> but also the reaction that produced the isotope  $^{277}\text{Cn}$  had a low yield (its cross-section was only 1 pb),<sup>[49]</sup> and thus did not provide enough hassium atoms for a chemical investigation.<sup>[45]</sup> The direct synthesis of  $^{269}\text{Hs}$  and  $^{270}\text{Hs}$  in the reaction  $^{248}\text{Cm}(^{26}\text{Mg},x\text{n})^{274-x}\text{Hs}$  ( $x = 4$  or  $5$ ) appeared more promising, as the cross-section for this reaction was somewhat larger, at 7 pb.<sup>[3][49]</sup> This yield was still around ten

times lower than that for the reaction used for the chemical characterization of bohrium.<sup>[49]</sup> New techniques for irradiation, separation, and detection had to be introduced before hassium could be successfully characterized chemically as a typical member of group 8 in early 2001.<sup>[3][49]</sup>

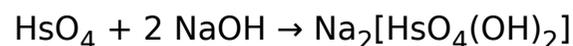
Ruthenium and osmium have very similar chemistry due to the lanthanide contraction, but iron shows some differences from them: for example, although ruthenium and osmium form stable tetroxides in which the metal is in the +8 oxidation state, iron does not.<sup>[49][51]</sup> Consequently, in preparation for the chemical characterization of hassium, researches focused on ruthenium and osmium rather than iron,<sup>[49]</sup> as hassium was expected to also be similar to ruthenium and osmium due to the actinide contraction.<sup>[3]</sup> Nevertheless, in the planned experiment to study hassocene (Hs(C<sub>5</sub>H<sub>5</sub>)<sub>2</sub>), ferrocene may also be used for comparison along with ruthenocene and osmocene.<sup>[6][62]</sup>

The first chemistry experiments were performed using gas thermochromatography in 2001, using <sup>172</sup>Os and <sup>173</sup>Os as a reference. During the experiment, 5 hassium atoms were synthesized using the reaction <sup>248</sup>Cm(<sup>26</sup>Mg,5n)<sup>269</sup>Hs. They were then thermalized and oxidized in a mixture of helium and oxygen gas to form the tetroxide.



The measured deposition temperature indicated that hassium(VIII) oxide is less volatile than osmium tetroxide, OsO<sub>4</sub>, and places hassium firmly in group 8.<sup>[3][27][48]</sup> However, the enthalpy of adsorption for HsO<sub>4</sub> measured, (−46 ± 2) kJ/mol, was significantly lower than what was predicted, (−36.7 ± 1.5) kJ/mol, indicating that OsO<sub>4</sub> was more volatile than HsO<sub>4</sub>, contradicting earlier calculations, which implied that they should have very similar volatilities. For comparison, the value for OsO<sub>4</sub> is (−39 ± 1) kJ/mol.<sup>[3]</sup> It is possible that hassium tetroxide interacts differently with the different chemicals (silicon nitride and silicon dioxide) used for the detector; further research is required, including more accurate measurements of the nuclear properties of <sup>269</sup>Hs and comparisons with RuO<sub>4</sub> in addition to OsO<sub>4</sub>.<sup>[3]</sup>

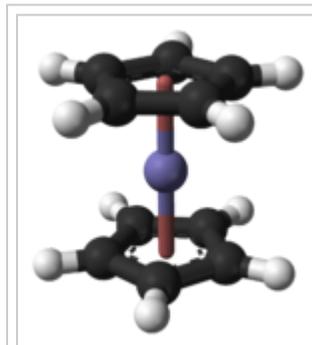
In 2004 scientists reacted hassium tetroxide and sodium hydroxide to form sodium hassate(VIII), a reaction well-known with osmium. This was the first acid-base reaction with a hassium compound, forming sodium hassate(VIII):<sup>[60]</sup>



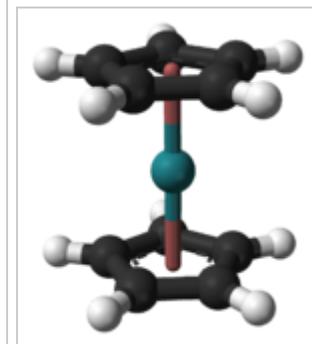
The team from the University of Mainz are planning to study the electrodeposition of hassium atoms using the new TASCA facility at the GSI. The current aim is to use the reaction  $^{226}\text{Ra}(^{48}\text{Ca},4n)^{270}\text{Hs}$ .<sup>[63]</sup> In addition, scientists at the GSI are hoping to utilize TASCA to study the synthesis and properties of the hassium(II) compound hassocene,  $\text{Hs}(\text{C}_5\text{H}_5)_2$ , using the reaction  $^{226}\text{Ra}(^{48}\text{Ca},xn)$ . This compound is analogous to the lighter ferrocene, ruthenocene, and osmocene, and is expected to have the two cyclopentadienyl rings in an eclipsed conformation like ruthenocene and osmocene and not in a staggered conformation like ferrocene.<sup>[6]</sup> Hassocene was chosen because it has hassium in the low formal oxidation state of +2 (although the bonding between the metal and the rings is mostly covalent in metallocenes) rather than the high +8 state which had previously been investigated, and relativistic effects were expected to be stronger in the lower oxidation state.<sup>[6]</sup> Many metals in the periodic table form metallocenes, so that trends could be more easily determined, and the highly symmetric structure of hassocene and its low number of atoms also make relativistic calculations easier. Hassocene should be a stable and highly volatile compound.<sup>[6]</sup>

## Source

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



In ferrocene, the cyclopentadienyl rings are in a staggered conformation.



In ruthenocene and osmocene, the cyclopentadienyl rings are in an eclipsed conformation. Hassocene is predicted to also have this structure.