

Tennessine

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Tennessine is a superheavy artificial chemical element with an atomic number of 117 and a symbol of **Ts**. It is the second-heaviest known element and penultimate element of the 7th period of the periodic table. As of 2016, fifteen tennessine atoms have been observed: six when it was first synthesized in 2010, seven in 2012, and two in 2014.

The discovery of tennessine was announced in Dubna, Russia, by a Russian–American collaboration in 2010, which makes it the most recently discovered element as of 2016. One of its daughter isotopes was created directly in 2011, partially confirming the results of the experiment. The experiment itself was repeated successfully by the same collaboration in 2012 and by a joint German–American team in 2014. In 2015, the Joint Working Party of the International Union of Pure and Applied Chemistry (IUPAC) and the International Union of Pure and Applied Physics, which evaluates claims of discovery of new elements, has recognized the element and assigned the priority to the Russian–American team. In June 2016, the IUPAC published a declaration stating that the discoverers suggested the name *tennessine* after Tennessee, United States.^[a] In November 2016, they officially adopted the name "tennessine".

Tennessine may be located in the "island of stability", a concept that explains why some superheavy elements are more stable compared to an overall trend of decreasing stability for elements beyond bismuth on the periodic table. The synthesized tennessine atoms have lasted tens and hundreds of milliseconds. In the periodic table, tennessine is expected to be a member of group 17, all other members of which are halogens.^[b] Some of its properties may significantly differ from those of the halogens due to relativistic effects. As a result, tennessine is expected to be a volatile metal that neither forms anions nor achieves high oxidation states. A few key properties, such as its melting and boiling points and its first ionization energy, are nevertheless expected to follow the periodic trends of the halogens.

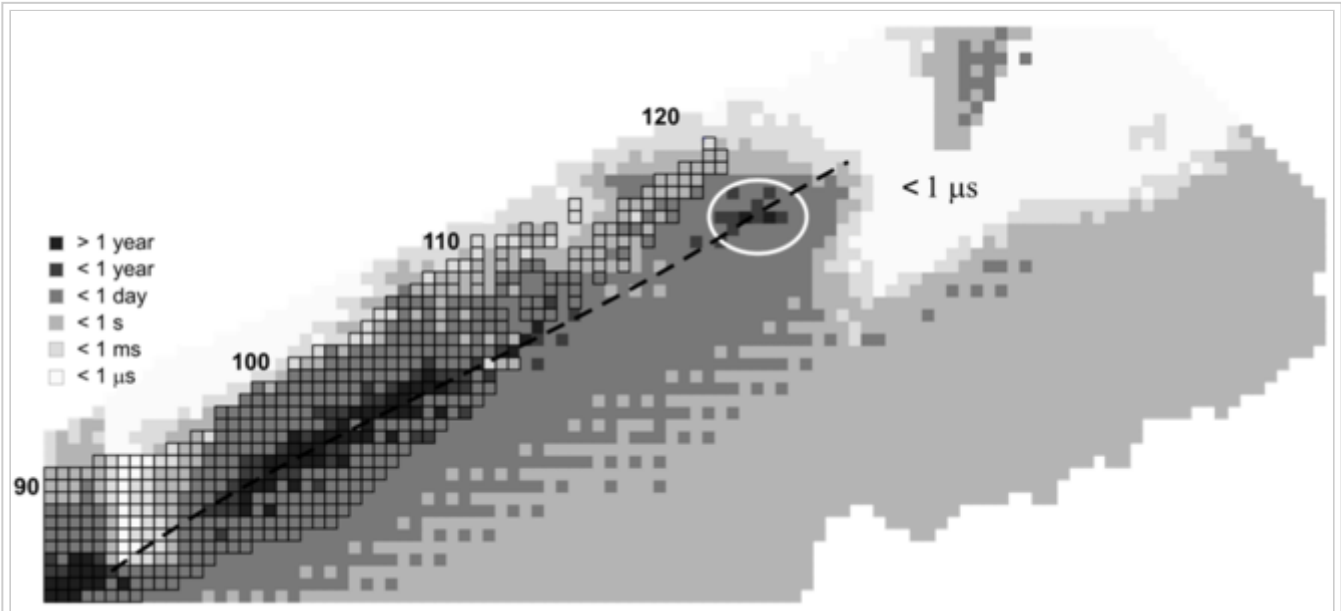
Predicted properties

Nuclear stability and isotopes

Tennessine, 117Ts

General properties	
Name, symbol	tennessine, Ts
Appearance	semimetallic <div>(<i>predicted</i>)^[1]</div>
Tennessine in the periodic table	
Atomic number (<i>Z</i>)	117
Group, block	group 17, p-block
Period	period 7
Element category	unknown, but probably a post-transition metal ^{[2][3]}
Standard atomic weight (<i>A</i>_r)	[294]
Electron configuration	[Rn] 5f¹⁴ 6d¹⁰ 7s² 7p⁵ (<i>predicted</i>) ^[4]
 <div>per shell</div>	2, 8, 18, 32, 32, 18, 7 (<i>predicted</i>)
Physical properties	
Phase	solid <div>(<i>predicted</i>)^{[4][5]}</div>
Melting point	623–823 K (350–550 °C, 662–1022 °F) <div>(<i>predicted</i>)^[4]</div>
Boiling point	883 K (610 °C,

The stability of nuclei quickly decreases with the increase in atomic number after curium, element 96, whose half-life is four orders of magnitude longer than that of any subsequent element. All isotopes with an atomic number above 101 undergo radioactive decay with half-lives of less than 30 hours. No elements with atomic numbers above 82 (after lead) have stable isotopes.^[36] Nevertheless, because of reasons not yet well understood, there is a slight increase of nuclear stability around atomic numbers 110–114, which leads to the appearance of what is known in nuclear physics as the "island of stability". This concept, proposed by University of California professor Glenn Seaborg, explains why superheavy elements last longer than predicted.^[37] Tennessine is the second-heaviest element created so far, and has a half-life of less than one second; this is longer than the predicted value used in the discovery report.^[24] The Dubna team believes that the synthesis of the element is direct experimental proof of the existence of the island of stability.^[38]



A chart of nuclide stability as used by the Dubna team in 2010. Characterized isotopes are shown with borders. According to the discoverers, synthesis of element 117 serves as definite proof of the existence of the "island of stability" (circled).^[38]

	1130 °F) (predicted) ^[4]
Density near r.t.	7.1–7.3 g/cm ³ (extrapolated) ^[5]
Atomic properties	
Oxidation states	−1, +1, +3, +5 (predicted) ^{[1][4]}
Ionization energies	1st: 742.9 kJ/mol (predicted) ^[4] 2nd: 1785.0–1920.1 kJ/mol (extrapolated) ^[5]
Atomic radius	empirical: 138 pm (predicted) ^[5]
Covalent radius	156–157 pm (extrapolated) ^[5]
Miscellanea	
CAS Number	54101-14-3
History	
Naming	after Tennessee region
Discovery	Joint Institute for Nuclear Research, Lawrence Livermore National Laboratory, Vanderbilt University and Oak Ridge National Laboratory (2010)
Most stable isotopes of tennessine	

It has been calculated that the isotope ²⁹⁵Ts would have a half-life of 18 ± 7 milliseconds and that it may be possible to produce this isotope via the same berkelium–calcium reaction used in the discoveries of the known isotopes, ²⁹³Ts and ²⁹⁴Ts. The chance of this reaction producing ²⁹⁵Ts is estimated to be, at most, one-seventh the chance of producing ²⁹⁴Ts.^{[39][40][41]} Calculations using a quantum tunneling model predict the existence of several isotopes of tennessine up to ³⁰³Ts. The most stable of these is expected to be ²⁹⁶Ts with an alpha-decay half-life of 40 milliseconds.^[42] A liquid drop model study on the element's isotopes shows similar results; it suggests a general trend of increasing stability for isotopes heavier than ³⁰¹Ts, with partial half-lives exceeding the age of the universe for the heaviest isotopes like ³³⁵Ts when beta decay is not considered.^[43]

iso	NA	half-life	DM	DE (MeV)	DP
²⁹⁴Ts ^[6]	syn	51 ⁺⁴¹ _{−16} ms	α	10.81	²⁹⁰ Mc
²⁹³Ts ^[7]	syn	22 ⁺⁸ _{−4} ms	α	11.11, 11.00, 10.91	²⁸⁹ Mc

Atomic and physical

Tennessine is expected to be a member of group 17 in the periodic table, below the five halogens; fluorine, chlorine, bromine, iodine, and astatine, each of which has seven valence electrons with a configuration of *ns*²*np*⁵.^{[44][e]} For tennessine, being in the seventh period (row) of the periodic table, continuing the trend would predict a valence electron configuration of 7s²7p⁵,^[4] and it would therefore be expected to behave similarly to the halogens in many respects that relate to this electronic state. However, going down group 17, the metallicity of the elements increases; for example, iodine already exhibits a metallic luster in the solid state, and astatine is often classified as a metalloid due to its properties being quite far from those of the four previous halogens. As such, an extrapolation based on periodic trends would predict tennessine to be a rather volatile post-transition metal.^[3]

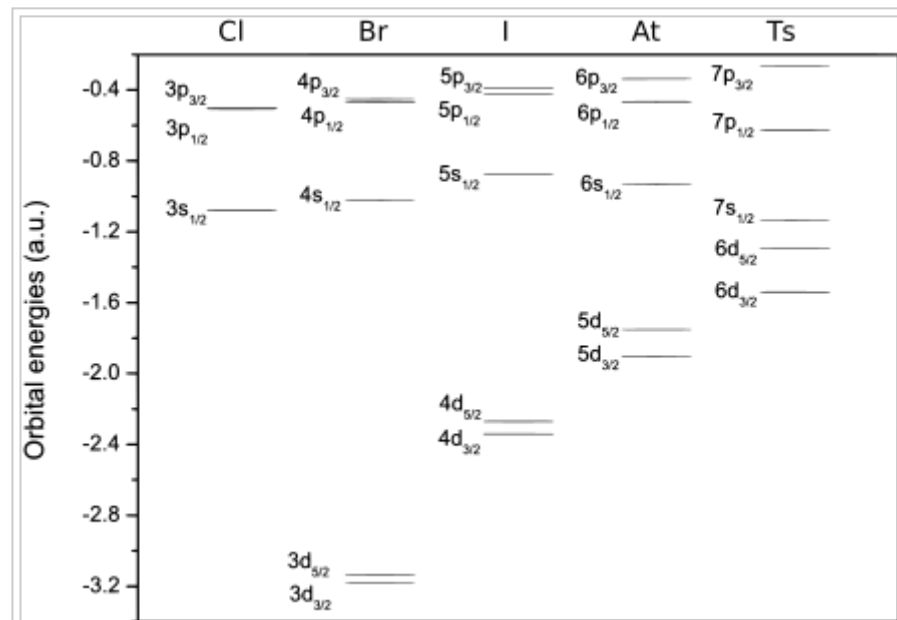
Calculations have confirmed the accuracy of this simple extrapolation, although experimental verification of this is currently impossible as the half-lives of the known tennessine isotopes are too short.^[3] Significant differences between tennessine and the previous halogens are likely to arise, largely due to spin-orbit interaction — the mutual interaction between the motion and spin of electrons. The spin-orbit interaction is especially strong for the superheavy elements because their electrons move faster — at velocities comparable to the speed of light — than those in lighter atoms.^[45] In tennessine atoms, this lowers the 7s and the 7p electron energy levels, stabilizing the corresponding electrons, although two of the 7p electron energy levels are more stabilized than the other four.^[46] The stabilization of the 7s electrons is called the inert pair effect; the effect that separates the 7p subshell into the more-stabilized and the less-stabilized parts is called subshell splitting. Computational chemists understand the split as a change of the second (azimuthal) quantum number *l* from 1 to 1/2 and 3/2 for the more-stabilized and less-stabilized parts of the 7p subshell, respectively.^{[47][f]} For many theoretical purposes, the valence electron configuration may be represented to reflect the 7p subshell split as 7s²7p²_{1/2}7p³_{3/2}.^[4]

Differences for other electron levels also exist. For example, the 6d electron levels (also split in two, with four being $6d_{3/2}$ and six being $6d_{5/2}$) are both raised, so they are close in energy to the 7s ones,^[46] although no 6d electron chemistry has been predicted for tennessine. The difference between the $7p_{1/2}$ and $7p_{3/2}$ levels is abnormally high; 9.8 eV.^[46] Astatine's 6p subshell split is only 3.8 eV,^[46] and its $6p_{1/2}$ chemistry has already been called "limited".^[48] These effects cause tennessine's chemistry to differ from those of its upper neighbors (see below).

Tennessine's first ionization energy—the energy required to remove an electron from a neutral atom—is predicted to be 7.7 eV, lower than those of the halogens, again following the trend.^[4] Like its neighbors in the periodic table, tennessine is expected to have the lowest electron affinity—energy released when an electron is added to the atom—in its group; 2.6 or 1.8 eV.^[4] The electron of the hypothetical hydrogen-like tennessine atom—oxidized so it has only one electron, Ts^{116+} —is predicted to move so quickly that its mass is 1.9 times that of a non-moving electron, a feature attributable to relativistic effects. For comparison, the figure for hydrogen-like astatine is 1.27 and the figure for hydrogen-like iodine is 1.08.^[49] Simple extrapolations of relativity laws indicate a contraction of atomic radius.^[49] Advanced calculations show that the radius of an tennessine atom that has formed one covalent bond would be 165 pm, while that of astatine would be 147 pm.^[50] With the seven outermost electrons removed, tennessine is finally smaller; 57 pm^[4] for tennessine and 61 pm^[51] for astatine.

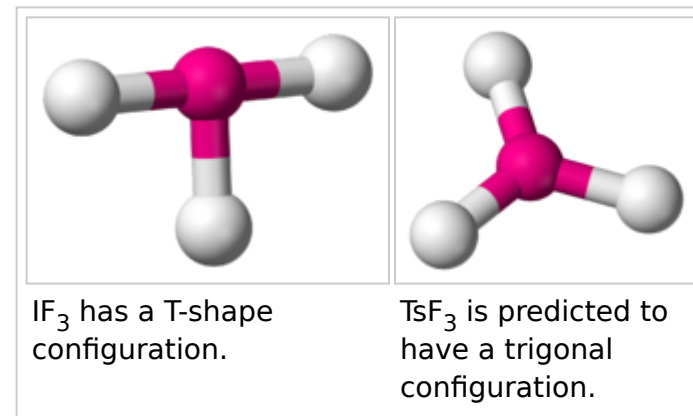
The melting and boiling points of tennessine are not known; earlier papers predicted about 350–500 °C and 550 °C, respectively,^[4] or 350–550 °C and 610 °C, respectively.^[52] These values exceed those of astatine and the lighter halogens, following periodic trends. A later paper predicts the boiling point of tennessine to be 345 °C^[53] (that of astatine is estimated as 309 °C,^[54] 337 °C,^[55] or 370 °C,^[56] although experimental values of 230 °C^[57] and 411 °C^[51] have been reported). The density of tennessine is expected to be between 7.1 and 7.3 g·cm^{−3}, continuing the trend of increasing density among the halogens; that of astatine is estimated to be between 6.2 and 6.5 g·cm^{−3}.^[5]

Chemical



Atomic energy levels of outermost s, p, and d electrons of chlorine (d orbitals not applicable), bromine, iodine, astatine, and tennessine

Unlike the previous group 17 elements, tennessine may not exhibit the chemical behavior common to the halogens.^[8] For example, the extant members of the group routinely accept an electron to achieve the more stable electronic configuration of a noble gas, one having eight electrons (octet) in its valence shell.^[58] This ability weakens as atomic weight increases going down the group; tennessine would be the least willing to accept an electron. Of the oxidation states it is predicted to form, -1 is expected to be the least common.^[4] The standard reduction potential of the Ts/Ts^- couple is predicted to be -0.25 V ; this value is negative and thus tennessine should not be reduced to the -1 oxidation state under standard conditions, unlike all the previous halogens.^[1]



There is another opportunity for tennessine to complete its octet—by forming a covalent bond. Like the halogens, when two tennessine atoms meet they are expected to form a Ts-Ts bond to give a diatomic molecule. Such molecules are commonly bound via single sigma bonds between the atoms; these are different from pi bonds, which are divided into two parts, each shifted in a direction perpendicular to the line between the atoms, and opposite one another rather than being located directly between the atoms they bind. Sigma bonding has been calculated to show a great antibonding character in the At_2 molecule and is not as favorable energetically. Tennessine is predicted to continue the trend; a strong pi character should be seen in the bonding of Ts_2 .^{[4][59]} The molecule tennessine chloride (TsCl)^[9] is predicted to go further, being bonded with a single pi bond.^[59]

Aside from the unstable -1 state, three more oxidation states are predicted; $+5$, $+3$, and $+1$. The $+1$ state should be especially stable because of the destabilization of the three outermost $7p_{3/2}$ electrons, forming a stable, half-filled subshell configuration;^[4] astatine shows similar effects.^[60] The $+3$ state should be important, again due to the destabilized $7p_{3/2}$ electrons.^[52] The $+5$ state is predicted to be uncommon because the $7p_{1/2}$ electrons are oppositely stabilized.^[4] The $+7$ state has not been shown—even computationally—to be achievable. Because the $7s$ electrons are greatly stabilized, it has been hypothesized that tennessine effectively has only five valence electrons.^[61]

The simplest possible tennessine compound would be the monohydride, TsH . The bonding is expected to be provided by a $7p_{3/2}$ electron of tennessine and the $1s$ electron of hydrogen. The non-bonding nature of the $7p_{1/2}$ spinor is because tennessine is expected not to form purely sigma or pi bonds.^[62] Therefore, the destabilized (thus expanded) $7p_{3/2}$ spinor is responsible for bonding.^[63] This effect lengthens the TsH molecule by 17 picometers compared with the overall length of 195 pm.^[62] Since the tennessine p electron bonds are two-thirds sigma, the bond is only two-thirds as strong as it would be if tennessine featured no spin-orbit interactions.^[62] The molecule thus follows the trend for halogen hydrides, showing an increase in bond length and a

decrease in dissociation energy compared to AtH.^[4] The molecules TlTs and NhTs may be viewed analogously, taking into account an opposite effect shown by the fact that the element's $p_{1/2}$ electrons are stabilized. These two characteristics result in a relatively small dipole moment (product of difference between electric charges of atoms and displacement of the atoms) for TlTs; only 1.67 D,^[h] the positive value implying that the negative charge is on the tennessine atom. For NhTs, the strength of the effects are predicted to cause a transfer of the electron from the tennessine atom to the nihonium atom, with the dipole moment value being -1.80 D.^[65] The spin-orbit interaction increases the dissociation energy of the TsF molecule because it lowers the electronegativity of tennessine, causing the bond with the extremely electronegative fluorine atom to have a more ionic character.^[62] Tennessine monofluoride should feature the strongest bonding of all group 17 element monofluorides.^[62]

VSEPR theory predicts a bent-T-shaped molecular geometry for the group 17 trifluorides. All known halogen trifluorides have this molecular geometry and have a structure of AX_3E_2 —a central atom, denoted A, surrounded by three ligands, X, and two unshared electron pairs, E. If relativistic effects are ignored, TsF₃ should follow its lighter congeners in having a bent-T-shaped molecular geometry. More sophisticated predictions show that this molecular geometry would not be energetically favored for TsF₃, predicting instead a trigonal planar molecular geometry (AX_3E_0). This shows that VSEPR theory may not be consistent for the superheavy elements.^[61] The TsF₃ molecule is predicted to be significantly stabilized by spin-orbit interactions; a possible rationale may be the large difference in electronegativity between tennessine and fluorine, giving the bond a partially ionic character.^[61]

Source

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