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Isotopes of hydrogen

Hydrogen ($_1$H) has three naturally occurring isotopes: ^{1}H, ^{2}H, and ^{3}H. ^{1}H and ^{2}H are stable, while ^{3}H has a half-life of 12.33(2) years.[3][nb 1] Heavier isotopes also exist; all are synthetic and have a half-life of less than 1 zeptosecond (10^{-21} s).[4][5] Of these, ^{5}H is the least stable, while ^{7}H is the most.

Hydrogen is the only element whose isotopes have different names that remain in common use today: ^{2}H is deuterium[6] and ^{3}H is tritium.[7] The symbols D and T are sometimes used for deuterium and tritium; IUPAC (International Union of Pure and Applied Chemistry) accepts said symbols, but recommends the standard isotopic symbols ^{2}H and ^{3}H, to avoid confusion in alphabetic sorting of chemical formulas.[8] ^{1}H, with no neutrons, may be called protium to disambiguate.[9] (During the early study of radioactivity, some other heavy radioisotopes were given names, but such names are rarely used today.)

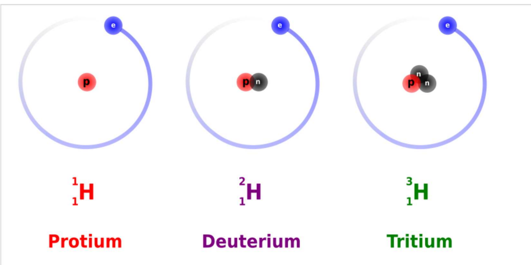
Isotopes of hydrogen ($_1$H)

Main isotopes			Decay	
	abundance	half-life ($t_{1/2}$)	mode	product
^{1}H	99.9855%	stable		
^{2}H	0.0145%	stable		
^{3}H	trace	12.33 y	β^-	^{3}He

Standard atomic weight $A_r°$(H)

[1.007 84, 1.008 11][1]

1.0080 ± 0.0002 (abridged)[2]



The three most stable isotopes of hydrogen: protium (*A* = 1), deuterium (*A* = 2), and tritium (*A* = 3).

List of isotopes

Note: "y" means year, but "ys" means yoctosecond (10^{-24} second).

Nuclide	*Z*	*N*	Isotopic mass (Da)[10] [n 1]	Half-life[11]	Decay mode[11] [n 2]	Daughter isotope [n 3]	Spin and parity[11] [n 4][n 5]	Natural abundance (mole fraction)		Note
								Normal proportion[11]	Range of variation	
^{1}H	1	0	1.007 825 031 898(14)	Stable[n 6][n 7]			1/2+	[0.999 72, 0.999 99][12]		Protium
^{2}H (D)[n 8][n 9]	1	1	2.014 101 777 844(15)	Stable			1+	[0.000 01, 0.000 28][12]		Deuterium
^{3}H (T)[n 10]	1	2	3.016 049 281 320(81)	12.33(2) y	β^-	**^{3}He**	1/2+	Trace[n 11]		Tritium
^{4}H	1	3	4.026 43(11)	139(10) ys	n	^{3}H	2−			
^{5}H	1	4	5.035 31(10)	86(6) ys	2n	^{3}H	(1/2+)			
^{6}H	1	5	6.044 96(27)	294(67) ys			2−#			
^{7}H	1	6	7.052 750(108)#	652(558) ys			1/2+#			
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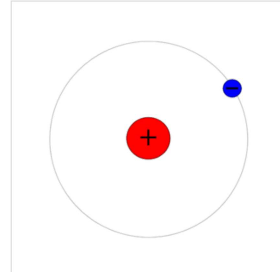
1. ( ) – Uncertainty (1*σ*) is given in concise form in parentheses after the corresponding last digits.
2. Modes of decay:
   n: Neutron emission
3. **Bold symbol** as daughter – Daughter product is stable.
4. ( ) spin value – Indicates spin with weak assignment arguments.
5. # – Values marked # are not purely derived from experimental data, but at least partly from trends of neighboring nuclides (TNN).
6. Unless proton decay occurs.
7. This and **^{3}He** are the only stable nuclides with more protons than neutrons.
8. Produced in Big Bang nucleosynthesis.
9. One of the few stable odd-odd nuclei
10. Produced in Big Bang nucleosynthesis, but not primordial, as all of it has decayed to **^{3}He**.[13]
11. Tritium occurs naturally as a cosmogenic nuclide.

Hydrogen-1 (protium)

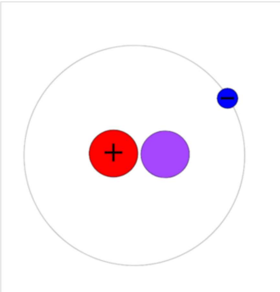
^{1}H (atomic mass 1.007 825 031 898(14) Da) is the most common hydrogen isotope, with an abundance of >99.98%. Its nucleus consists of only a single proton, so it has the formal name **protium**.

The proton has never been observed to decay, so ^{1}H is considered stable. Some Grand Unified Theories proposed in the 1970s predict that proton decay can occur with a half-life between 10^{28} and 10^{36} years.[14] If so, then ^{1}H (and all nuclei now believed to be stable) are only observationally stable. As of 2018, experiments have shown that the mean lifetime of the proton is $>3.6 \times 10^{29}$ years.[15]



^{1}H consists of 1 proton and 1 electron: the only stable nuclide with no neutrons (see diproton for a discussion of why no others exist)

Hydrogen-2 (deuterium)



Deuterium consists of 1 proton, 1 neutron, and 1 electron.

Deuterium, **^{2}H** (atomic mass 2.014 101 777 844(15) Da), the other stable hydrogen isotope, has one proton and one neutron in its nucleus, called a deuteron. ^{2}H comprises 26–184 ppm (by population, not mass) of hydrogen on Earth; the lower number tends to be found in hydrogen gas and higher enrichment (150 ppm) is typical of seawater. Deuterium on Earth has been enriched with respect to its initial concentration in the Big Bang and outer Solar System (≈27 ppm, atom fraction) and older parts of the Milky Way (≈23 ppm). Presumably the differential concentration of deuterium in the inner Solar System is due to the lower volatility of deuterium gas and compounds, enriching deuterium fractions in comets and planets exposed to significant heat from the Sun over billions of years of Solar System evolution.

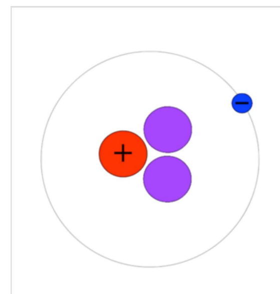
Deuterium is not radioactive, and is not a significant toxicity hazard. Water enriched in ^{2}H is called heavy water. Deuterium and its compounds are used as a non-radioactive label in chemical experiments and in solvents for ^{1}H-nuclear magnetic resonance spectroscopy. Heavy water is used as a neutron moderator and coolant for nuclear reactors. Deuterium is also a potential fuel for commercial nuclear fusion.

Hydrogen-3 (tritium)

Tritium, **^{3}H** (atomic mass 3.016 049 281 320(81) Da), has one proton and two neutrons in its nucleus (triton). It is radioactive, β^{-} decaying into helium-3 with half-life 12.33(2) years.[nb 1][3] Traces of ^{3}H occur naturally due to cosmic rays interacting with atmospheric gases. ^{3}H has also been released in nuclear tests. It is used in fusion bombs, as a tracer in isotope geochemistry, and in self-powered lighting devices.

The most common way to produce ^{3}H is to bombard a natural isotope of lithium, ^{6}Li, with neutrons in a nuclear reactor.

Tritium can be used in chemical and biological labeling experiments as a radioactive tracer.[16][17] Deuterium–tritium fusion uses ^{2}H and ^{3}H as its main reactants, giving energy through the loss of mass when the two nuclei collide and fuse at high temperatures.



Tritium consists of 1 proton, 2 neutrons, and 1 electron.

Hydrogen-4

^{4}H (atomic mass 4.026 43(11)), with one proton and three neutrons, is a highly unstable isotope. It has been synthesized in the laboratory by bombarding tritium with fast-moving deuterons;[18] the triton captured a neutron from the deuteron. The presence of ^{4}H was deduced by detecting the emitted protons. It decays by neutron emission into ^{3}H with a half-life of 139(10) ys (or $1.39(10) \times 10^{-22}$ s).

In the 1955 satirical novel *The Mouse That Roared*, the name **quadium** was given to the ^{4}H that powered the *Q-bomb* that the Duchy of Grand Fenwick captured from the United States.

Hydrogen-5

^{5}H (atomic mass 5.035 31(10)), with one proton and four neutrons, is highly unstable. It has been synthesized in the lab by bombarding tritium with fast-moving tritons;[18][19] one triton captures two neutrons from the other, becoming a nucleus with one proton and four neutrons. The remaining proton may be detected, and the existence of ^{5}H deduced. It decays by double neutron emission into ^{3}H and has a half-life of 86(6) ys ($8.6(6) \times 10^{-23}$ s) – the shortest half-life of any known nuclide.[3]

Hydrogen-6

^{6}H (atomic mass 6.044 96(27)) has one proton and five neutrons. It has a half-life of 294(67) ys ($2.94(67) \times 10^{-22}$ s).

Hydrogen-7

^{7}H (atomic mass 7.052 75(108)) has one proton and six neutrons. It was first synthesized in 2003 by a group of Russian, Japanese and French scientists at Riken's Radioactive Isotope Beam Factory by bombarding hydrogen with helium-8 atoms; all six of the helium-8's neutrons were donated to the hydrogen nucleus. The two remaining protons were detected by the "Riken telescope", a device made of several layers of sensors, positioned behind the target of the RI Beam cyclotron.[5] ^{7}H has a half-life of 652(558) ys ($6.52(558) \times 10^{-22}$ s).[3]

Decay chains

^{4}H and ^{5}H decay directly to ^{3}H, which then decays to stable ^{3}He. Decay of the heaviest isotopes, ^{6}H and ^{7}H, has not been experimentally observed.[11]

$$^3_1\mathrm{H} \xrightarrow{12.32\ \mathrm{y}} {}^3_2\mathrm{He} + \mathrm{e}^-$$
$$^4_1\mathrm{H} \xrightarrow{139\ \mathrm{ys}} {}^3_1\mathrm{H} + {}^1_0\mathrm{n}$$
$$^5_1\mathrm{H} \xrightarrow{86\ \mathrm{ys}} {}^3_1\mathrm{H} + 2\,{}^1_0\mathrm{n}$$

Decay times are in yoctoseconds (10^{-24} s) for all these isotopes except ^{3}H, which is in years.

See also

- Hydrogen atom
- Hydrogen isotope biogeochemistry
- Hydrogen-4.1 (Muonic helium)
- Muonium – acts like an exotic light isotope of hydrogen
- Media related to Isotopes of hydrogen at Wikimedia Commons

Notes

1. Note that NUBASE2020 uses the tropical year to convert between years and other units of time, not the Gregorian year. The relationship between years and other time units in NUBASE2020 is as follows: 1 y = 365.2422 d = 31 556 926 s

References

1. "Standard Atomic Weights: Hydrogen" (https://www.ciaaw.org/hydrogen.htm). CIAAW. 2009.
2. Prohaska, Thomas; Irrgeher, Johanna; Benefield, Jacqueline; Böhlke, John K.; Chesson, Lesley A.; Coplen, Tyler B.; Ding, Tiping; Dunn, Philip J. H.; Gröning, Manfred; Holden, Norman E.; Meijer, Harro A. J. (2022-05-04). "Standard atomic weights of the elements 2021 (IUPAC Technical Report)" (https://www.degruyter.com/document/doi/10.1515/pac-2019-0603/html). *Pure and Applied Chemistry*. doi:10.1515/pac-2019-0603 (https://doi.org/10.1515%2Fpac-2019-0603). ISSN 1365-3075 (https://search.worldcat.org/issn/1365-3075).
3. Kondev, F. G.; Wang, M.; Huang, W. J.; Naimi, S.; Audi, G. (March 2021). "The NUBASE2020 evaluation of nuclear physics properties \ast" (https://doi.org/10.1088%2F1674-1137%2Fabddae). *Chinese Physics C*. **45** (3): 030001. Bibcode:2021ChPhC..45c0001K (https://ui.adsabs.harvard.edu/abs/2021ChPhC..45c0001K). doi:10.1088/1674-1137/abddae (https://doi.org/10.1088%2F1674-1137%2Fabddae). ISSN 1674-1137 (https://search.worldcat.org/issn/1674-1137). S2CID 233794940 (https://api.semanticscholar.org/CorpusID:233794940).
4. Y. B. Gurov; et al. (2004). "Spectroscopy of superheavy hydrogen isotopes in stopped-pion absorption by nuclei". *Physics of Atomic Nuclei*. **68** (3): 491–497. Bibcode:2005PAN....68..491G (https://ui.adsabs.harvard.edu/abs/2005PAN....68..491G). doi:10.1134/1.1891200 (https://doi.org/10.1134%2F1.1891200). S2CID 122902571 (https://api.semanticscholar.org/CorpusID:122902571).
5. A. A. Korsheninnikov; et al. (2003). "Experimental Evidence for the Existence of ^{7}H and for a Specific Structure of ^{8}He". *Physical Review Letters*. **90** (8): 082501. Bibcode:2003PhRvL..90h2501K (https://ui.adsabs.harvard.edu/abs/2003PhRvL..90h2501K). doi:10.1103/PhysRevLett.90.082501 (https://doi.org/10.1103%2FPhysRevLett.90.082501). PMID 12633420 (https://pubmed.ncbi.nlm.nih.gov/12633420).
6. IUPAC, *Compendium of Chemical Terminology*, 2nd ed. (the "Gold Book") (1997). Online corrected version: (2006–) "deuterium (https://goldbook.iupac.org/terms/view/D01648.html)". doi:10.1351/goldbook.D01648 (https://doi.org/10.1351%2Fgoldbook.D01648)
7. IUPAC, *Compendium of Chemical Terminology*, 2nd ed. (the "Gold Book") (1997). Online corrected version: (2006–) "tritium (https://goldbook.iupac.org/terms/view/T06513.html)". doi:10.1351/goldbook.T06513 (https://doi.org/10.1351%2Fgoldbook.T06513)
8. International Union of Pure and Applied Chemistry (2005). *Nomenclature of Inorganic Chemistry* (IUPAC Recommendations 2005). Cambridge (UK): RSC–IUPAC. ISBN 0-85404-438-8. p. 48. Electronic version. (https://old.iupac.org/publications/books/rbook/Red_Book_2005.pdf)
9. IUPAC, *Compendium of Chemical Terminology*, 2nd ed. (the "Gold Book") (1997). Online corrected version: (2006–) "protium (https://goldbook.iupac.org/terms/view/P04903.html)". doi:10.1351/goldbook.P04903 (https://doi.org/10.1351%2Fgoldbook.P04903)
10. Wang, Meng; Huang, W.J.; Kondev, F.G.; Audi, G.; Naimi, S. (2021). "The AME 2020 atomic mass evaluation (II). Tables, graphs and references*". *Chinese Physics C*. **45** (3): 030003. doi:10.1088/1674-1137/abddaf (https://doi.org/10.1088%2F1674-1137%2Fabddaf).
11. Kondev, F. G.; Wang, M.; Huang, W. J.; Naimi, S.; Audi, G. (2021). "The NUBASE2020 evaluation of nuclear properties" (https://www-nds.iaea.org/amdc/ame2020/NUBASE2020.pdf) (PDF). *Chinese Physics C*. **45** (3): 030001. doi:10.1088/1674-1137/abddae (https://doi.org/10.1088%2F1674-1137%2Fabddae).
12. "Atomic Weight of Hydrogen" (http://ciaaw.org/hydrogen.htm). *CIAAW*. Retrieved 24 June 2021.
13. Coc, Alain (2009). "Big-bang nucleosynthesis: A probe of the early Universe". *Nuclear Instruments and Methods in Physics Research Section A*. **611** (2–3): 224–230. Bibcode:2009NIMPA.611..224C (https://ui.adsabs.harvard.edu/abs/2009NIMPA.611..224C). doi:10.1016/j.nima.2009.07.052 (https://doi.org/10.1016%2Fj.nima.2009.07.052).
14. Ed Kearns (2009). "Grand Unified Theories and Proton Decay" (http://physics.bu.edu/NEPPSR/TALKS-2009/Kearns_GUTs_ProtonDecay.pdf) (PDF). Boston University. p. 15.
15. The SNO+ Collaboration; Anderson, M.; Andringa, S.; Arushanova, E.; Asahi, S.; Askins, M.; Auty, D. J.; Back, A. R.; Barnard, Z.; Barros, N.; Bartlett, D. (2019-02-20). "Search for invisible modes of nucleon decay in water with the SNO+ detector" (https://doi.org/10.1103%2FPhysRevD.99.032008). *Physical Review D*. **99** (3): 032008. arXiv:1812.05552 (https://arxiv.org/abs/1812.05552). Bibcode:2019PhRvD..99c2008A (https://ui.adsabs.harvard.edu/abs/2019PhRvD..99c2008A). doi:10.1103/PhysRevD.99.032008 (https://doi.org/10.1103%2FPhysRevD.99.032008). S2CID 96457175 (https://api.semanticscholar.org/CorpusID:96457175).
16. Pfizer Japan. "SARS-CoV-2 mRNA Vaccine (BNT162, PF-07302048)" (https://web.archive.org/web/20220324171847/http://www.pmda.go.jp/drugs/2021/P20210212001/672212000_30300AMX00231_I100_1.pdf#page=16) (PDF). *Pharmaceuticals and Medical Devices Agency (Japan)*. 2.6.5.5B, pp. 6–8. Archived from the original (http://www.pmda.go.jp/drugs/2021/P20210212001/672212000_30300AMX00231_I100_1.pdf#page=16) (PDF) on 24 March 2022. Retrieved 5 June 2021. "[^{3}H]-Labelled LNP-mRNA"

17. Green, Joanne Balmer; Green, Michael H. (2020). "Vitamin A Absorption Determined in Rats Using a Plasma Isotope Ratio Method" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7330459). *The Journal of Nutrition*. **150** (7): 1977–1981. doi:10.1093/jn/nxaa092 (https://doi.org/10.1093%2Fjn%2Fnxaa092). PMC 7330459 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7330459). PMID 32271921 (https://pubmed.ncbi.nlm.nih.gov/32271921).
18. G. M. Ter-Akopian; et al. (2002). "Hydrogen-4 and Hydrogen-5 from t+t and t+d transfer reactions studied with a 57.5-MeV triton beam". *AIP Conference Proceedings*. **610**: 920–924. Bibcode:2002AIPC..610..920T (https://ui.adsabs.harvard.edu/abs/2002AIPC..610..920T). doi:10.1063/1.1470062 (https://doi.org/10.1063%2F1.1470062).
19. A. A. Korsheninnikov; et al. (2001). "Superheavy Hydrogen ^5H". *Physical Review Letters*. **87** (9): 92501. Bibcode:2001PhRvL..87i2501K (https://ui.adsabs.harvard.edu/abs/2001PhRvL..87i2501K). doi:10.1103/PhysRevLett.87.092501 (https://doi.org/10.1103%2FPhysRevLett.87.092501). PMID 11531562 (https://pubmed.ncbi.nlm.nih.gov/11531562).

Further reading

- Dumé, B. (7 March 2003). "Hydrogen-7 makes its debut" (http://physicsworld.com/cws/article/news/2003/mar/07/hydrogen-7-makes-its-debut). *Physics World*.