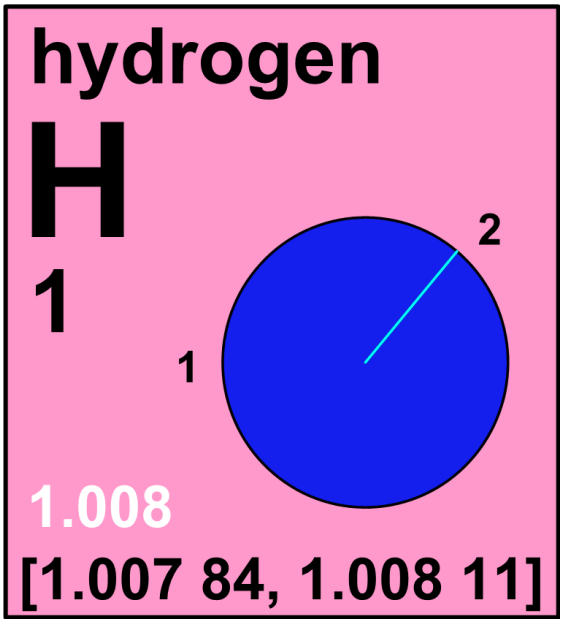
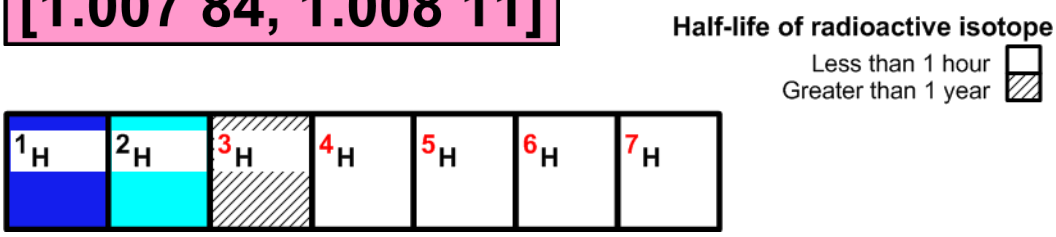
4.1 hydrogen



Stable isotope	Relative atomic mass	Mole fraction
^{1}H	1.007 825 0322	[0.999 72, 0.999 99]
^{2}H	2.014 101 7781	[0.000 01, 0.000 28]



4.1.1 Hydrogen isotopes in Earth/planetary science

Molecules, atoms, and ions of the **stable isotopes** of hydrogen possess slightly different physical and chemical properties, and they commonly will be fractionated during physical, chemical, and biological processes, giving rise to variations in **isotopic abundances** and in **atomic weights** (Fig. 4.1.1). Hydrogen has the largest relative mass difference among its **isotopes** and consequently exhibits the largest variation in **isotopic composition** of any **element** that does not have radioactive or **radiogenic** isotopes. Ranges in the stable isotopic composition of naturally occurring hydrogen-bearing materials are shown in Figure 4.1.1. These variations enable hydrogen isotopes to be used as **tracers** in environmental studies [10].

A primary use of stable hydrogen isotopes is in isotope hydrology. Although the evolution of the stable hydrogen and oxygen isotopic composition of precipitation begins with evaporation of water from the oceans, their local and global relationship arises primarily from equilibrium **isotopic fractionation** of heavier (^{2}H and ^{18}O) and lighter isotopes (^{1}H and ^{16}O) of hydrogen and oxygen during condensation as a **tropospheric** vapor mass follows a trajectory to higher latitudes and over continents [11, 12]. As a consequence, the hydrogen isotopic composition of precipitation, rivers, and tap waters varies with elevation, season, and distance from the ocean-continent boundary. Figure 4.1.2 shows the variation in atomic weight of hydrogen in water from rivers across the United States. These variations in hydrogen isotopic

composition of environmental water are often combined with stable oxygen isotopic compositions and have been used to identify the origin of water and to investigate the interaction between groundwater and surface water (e.g., lakes, streams, and rivers) [13].

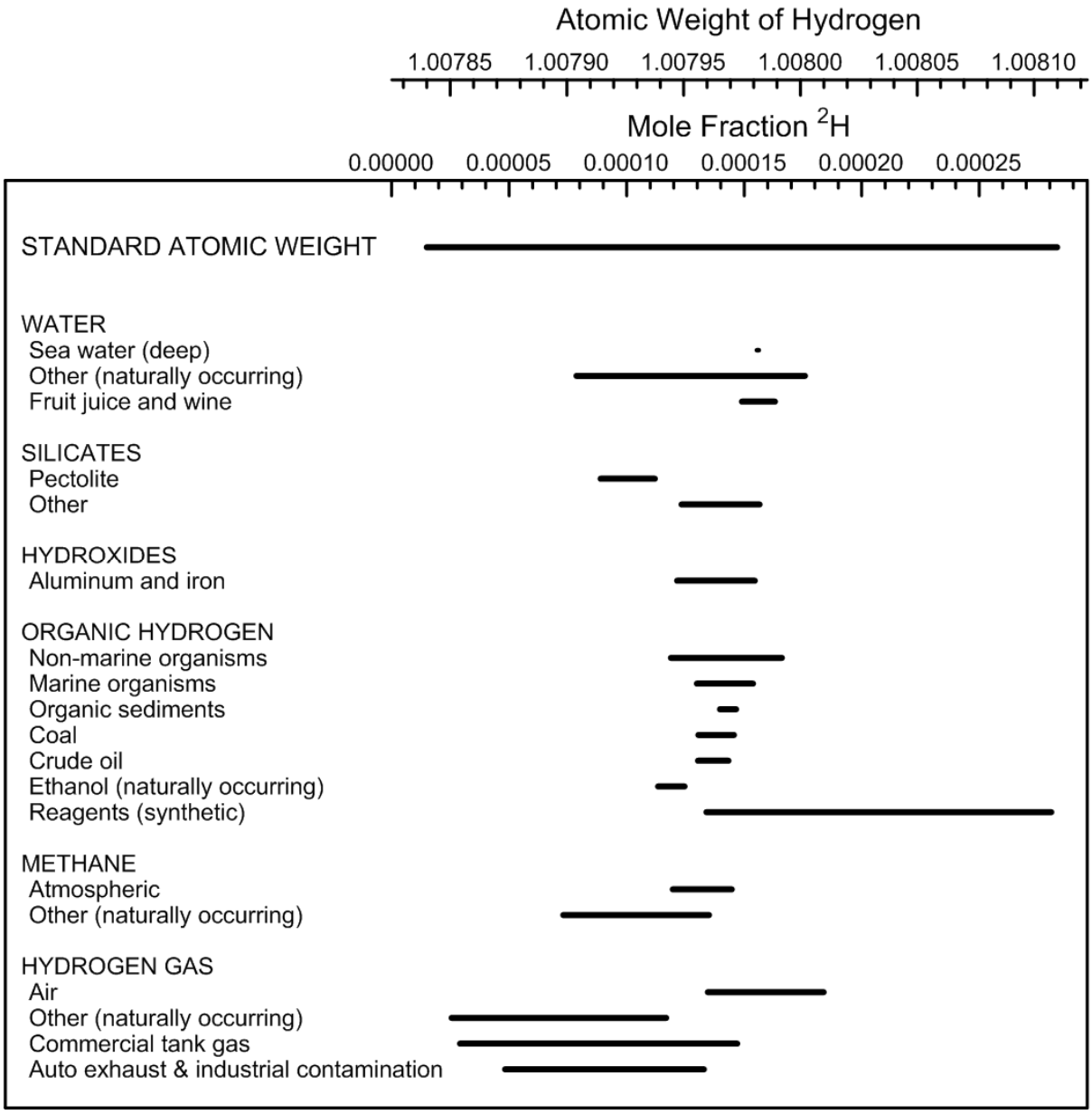


Fig. 4.1.1: Variation in **atomic weight** with **isotopic composition** of selected hydrogen-bearing materials (modified from [10, 14]).

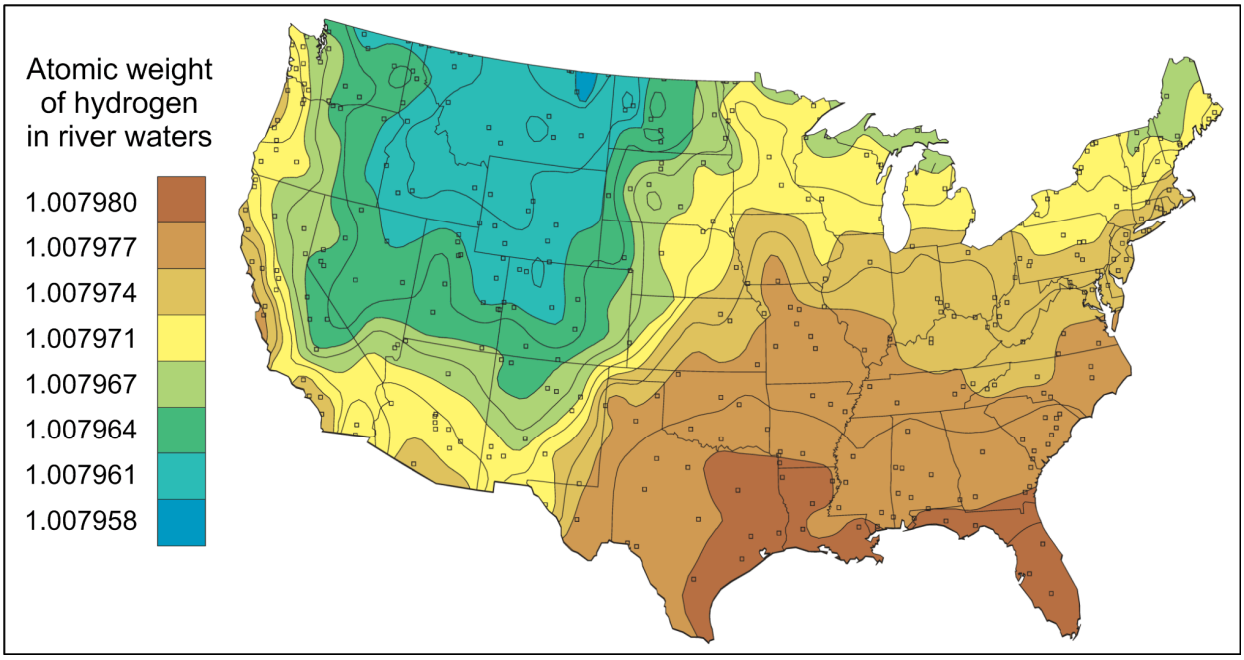


Fig. 4.1.2: Variation in atomic weight of hydrogen in river waters across the continental United States (modified from [13]). Blue color indicates waters most depleted in ^{2}H (resulting in lower atomic weight of hydrogen) and brown color indicates those most enriched in ^{2}H (resulting in higher atomic weight of hydrogen).

4.1.2 Hydrogen isotopes in forensic science and anthropology

Measurements of relative ^{2}H abundances are used to determine the breeding grounds of many species of migrant songbirds. These species of songbirds only grow their feathers before migration, and they grow them on or close to their breeding grounds. Therefore, the isotopic composition of a bird's feathers correlates to the isotopic composition of the growing season's precipitation [15-17].

Measurements of relative ^{2}H abundances of human hair samples collected at archeological sites are used to determine the geographic region in which a subject lived based on the hydrogen isotopic composition of the water they drank. This is possible because hair stores a daily record of hydrogen isotopic composition of intake water, which correlates to local **meteoric water** [15, 18].

4.1.3 Hydrogen isotopes in geochronology

^{3}H (tritium), with a **half-life** of 12.31 years, decays to ^{3}He. The relative variations in $n(^{3}He)/n(^{3}H)$ ratios can be interpreted in terms of elapsed time for dating purposes. Dates of groundwater recharge (water moving downward from the surface), where large amounts of ^{3}H were received from precipitation following **thermonuclear bomb** test periods, come from elapsed time since a water mass became isolated from the atmosphere in the time range from the mid-1950s to the present [12].

4.1.4 Hydrogen isotopes in industry

^{3}H is used for self-**luminous** exit signs in aircraft and commercial buildings. It is found in luminous dials, gauges, wristwatches, and luminous paints [19]. ^{2}H, in the form of **heavy water**, is used in CANDU (**CAN**ada **D**euterium **U**ranium) nuclear reactors as a moderator and coolant [20].

4.1.5 Hydrogen isotopes in medicine

^{2}H is used for isotopic labeling of drugs and nutrients to trace their uptake and **metabolism** in the human body [21, 22]. ^{2}H, in the form of heavy water, is used to study human metabolism. For example, ^{2}H is used in combination with ^{18}O (double labeled water) for measuring energy expenditure [23].