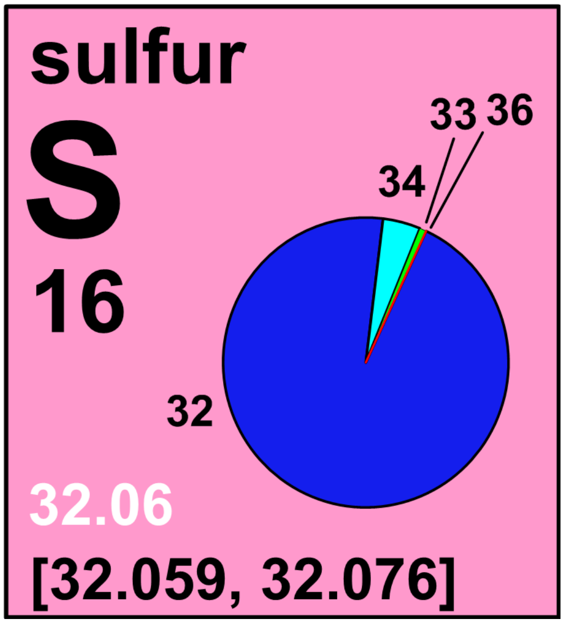
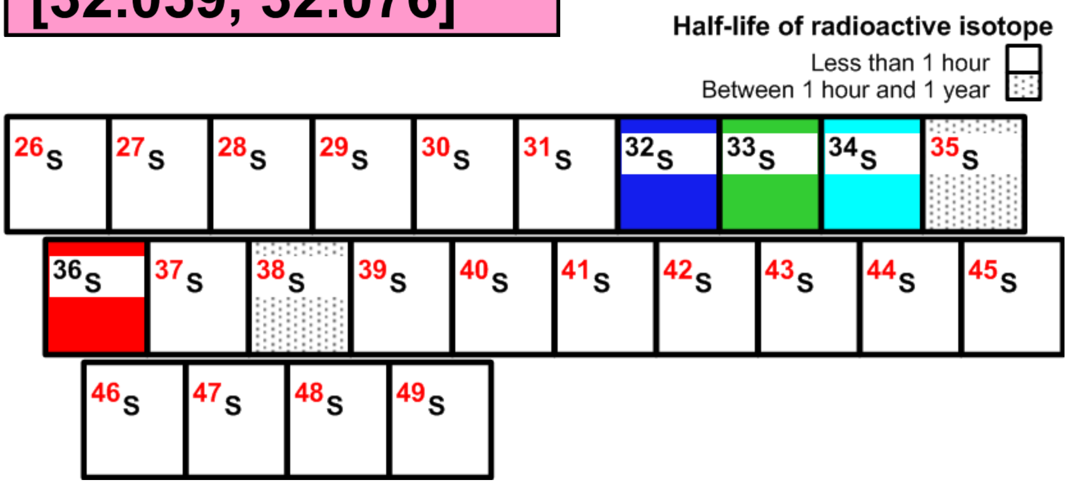
4.16 sulfur



Stable isotope	Relative atomic mass	Mole fraction
^{32}S	31.972 071 174	[0.9441, 0.9529]
^{33}S	32.971 458 910	[0.007 29, 0.007 97]
^{34}S	33.967 8670	[0.0396, 0.0477]
^{36}S	35.967 081	[0.000 129, 0.000 187]



4.16.1 Sulfur isotopes in biology

The stable sulfur **isotope-amount ratio** ($n(^{34}S)/n(^{32}S)$) has been used to distinguish whether animal tissues grew in freshwater or in marine ecosystems. The **isotopes** do not fractionate (separate) substantially with trophic influences (the movement of sulfur through and into plant and animal systems), and the isotope-amount ratio $n(^{34}S)/n(^{32}S)$ usually is substantially different between freshwater and marine environments. As an example, by analyzing sulfur isotope-amount ratios in bird feathers, the environment in which the bird was living when these feathers developed can be determined. This enables one to track bird habitats and migration patterns throughout the year (Figure 4.16.1) [138].

4.16.2 Sulfur isotopes in Earth/planetary science

Molecules, atoms, and ions of the **stable isotopes** of sulfur 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**. There are substantial variations in the isotopic abundances of sulfur in natural terrestrial materials (Figure 4.16.2). These variations are useful in investigating the origin of substances and studying environmental, hydrological, and geological processes [10, 14]. The isotope-amount ratio $n(^{34}\text{S})/n(^{32}\text{S})$ can be used to trace natural and **anthropogenic** sources of sulfur. Examples include studies of acid mine drainage, the cycling of sulfur in agricultural watersheds, groundwater contamination from landfills, and sources of salinity in coastal aquifers [139-141].

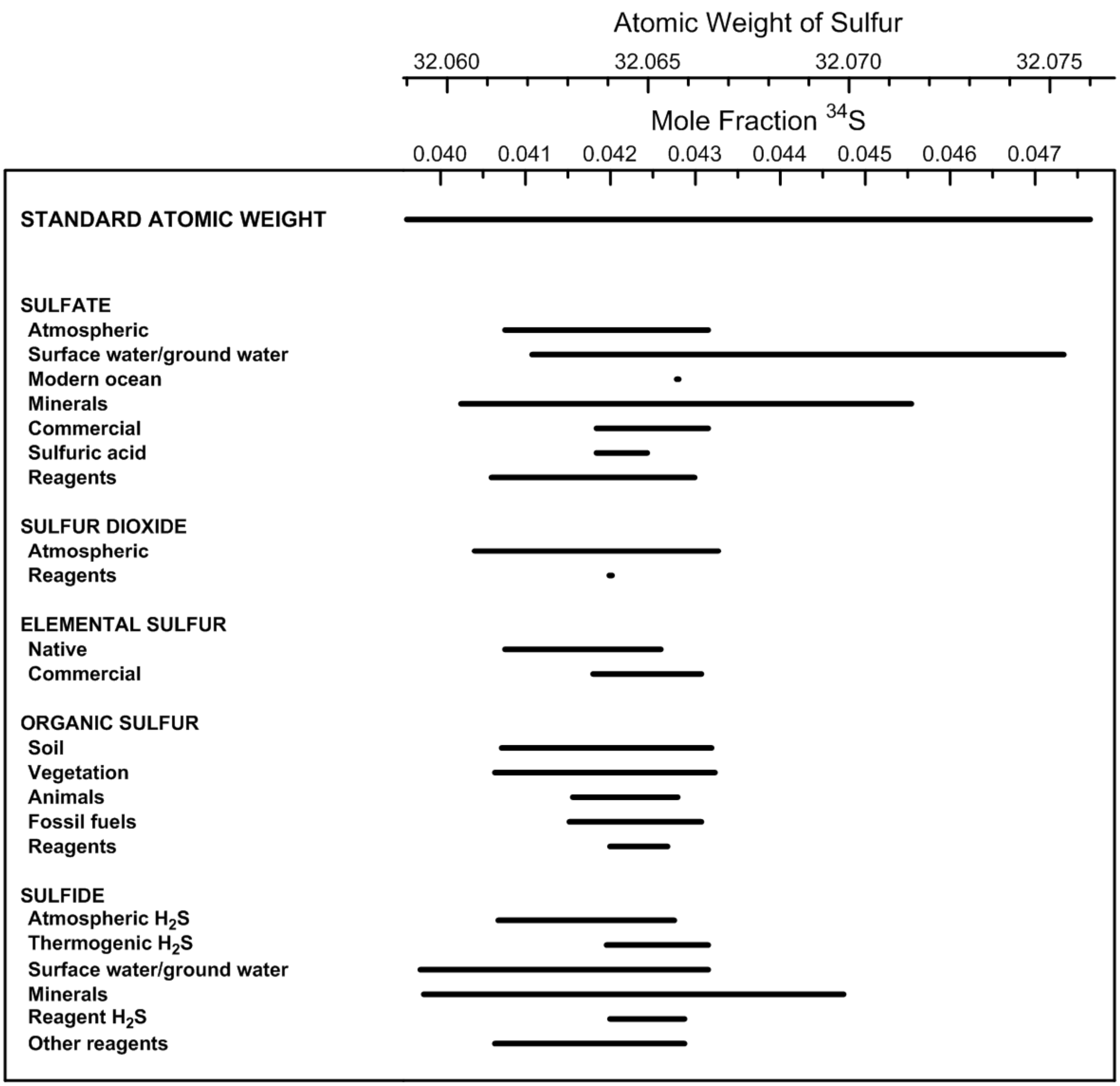


Fig. 4.16.1: Variation in **atomic weight** with **isotopic composition** of selected sulfur-bearing materials (modified from [10, 14]).

4.16.3 Sulfur isotopes in forensic science and anthropology

The isotope-amount ratio $n(^{34}S)/n(^{32}S)$ can be used to authenticate the dietary source of cattle. First, stable isotopes are measured to infer the dietary source of the cattle. Once the source of the diet is found, the **isotopic compositions** can be traced in certain muscle groups of the cattle and can be used to determine if the diet of the animal has been changed or if the feed is consistent with what the animal has been claimed to have been fed [142].

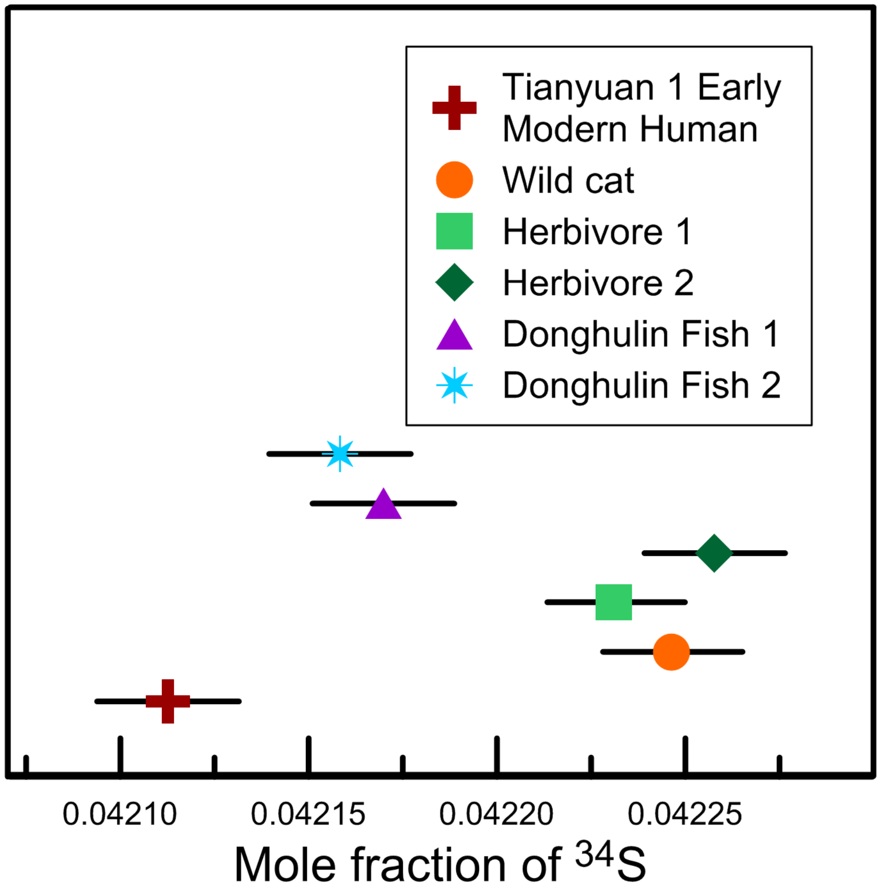


Fig. 4.16.2: Sulfur **isotopic abundances** of Tianyuan 1 early modern human found in Eurasia, three terrestrial animals from Tianyuan Cave (Tianyuandong) in the Zhoukoudian region of China, and two fish from Donghulin (modified from [143]). Based on sulfur, carbon, and nitrogen isotopic analyses of bones from the early modern human and the associated animals in Tianyuan Cave and the Donghulin site, Hu *et al.* [143] conclude that the human most likely obtained a substantial portion of its protein from a freshwater ecosystem, probably from freshwater fish.

4.16.4 Sulfur isotopes in geochronology

^{35}S has a **half-life** of 87 days, which is an ideal duration for use as a conservative tracer in atmospheric processes. $^{35}SO_2$ gas is produced as a natural product of argon exposure to **cosmic rays** in the atmosphere. Because $^{35}SO_2$ gas is present in the atmosphere and then precipitates and falls as moisture in the form of $^{35}SO_4^{2-}$, ^{35}S can act as a tracer to study air mass transport dynamics and atmospheric oxidation capacity [144]. Analyses of ^{35}S in lake water and precipitation can also be used as a tracer to monitor contributions of sulfur that originated in precipitation to surface waters. If a water tests positive for the isotope ^{35}S, it provides evidence that the water had been affected by recent (<~1 year) precipitation [145-147]. ^{35}S is used in direct labeling of elemental sulfur or sulfate sources to trace the fate of sulfur in fertilizers [139].