Natural materials are made of natural existing elements or nuclides. Some of these elements have more than one stable isotope, and some may have long-live isotopes. **Stable nuclides are the stable isotopes of all elements.**

Elements with atomic number less than 83 have at least one stable isotope except technetium (Tc, Z = 41) and promethium (Pm, Z = 61). Elements with atomic number between 84 and 92 (inclusive) are present, but some only as decay products of uranium or thorium. This aspect is discussed in decay families.

### Features of Stable Nuclides

There are several features with respect to stable nuclides.

#### Numbers of protons and neutrons

- Only $^1\text{H}$ and $^3\text{He}$ have more protons than neutrons.
- Nuclides $^2\text{D}$, $^4\text{He}$, $^6\text{Li}$, $^{10}\text{B}$, $^{12}\text{C}$, $^{14}\text{N}$, $^{16}\text{O}$, $^{20}\text{Ne}$, $^{24}\text{Mg}$, $^{28}\text{Si}$, $^{32}\text{S}$, $^{36}\text{Ar}$, and $^{40}\text{Ca}$ have equal number of protons and neutrons. All other nuclides have more neutrons than protons.
- Only $^2\text{D}$, $^6\text{Li}$, $^{10}\text{B}$, and $^{14}\text{N}$ have equal, but odd number of protons and neutrons.
- Heavy stable nuclides have more neutrons per proton than light ones have.

#### Magic numbers of protons and neutrons

- Elements with $Z = 2$, 8, 20, 28, 50, and 82 have many isotopes. Thus, these numbers are called **magic numbers**. For example, the stable isotopes of calcium ($Z = 20$) have mass numbers 40, 42, 43, 44, 46, and 48, a total of six. There are a total of ten stable isotopes of tin, $^{112}$Sn, $^{114}$Sn, $^{115}$Sn, $^{116}$Sn, $^{117}$Sn, $^{118}$Sn, $^{119}$Sn, $^{120}$Sn, $^{122}$Sn, & $^{124}$Sn.
- In our discussion of radioactive decay families, you have noticed that the stable element of three families is lead ($Z = 82$), and it has a magic number of protons. The stable nuclide for the fourth family is $^{209}\text{Bi}$, and it has a magic number (126) of neutrons. This is the stable nuclide with the highest atomic number.
- **Double-magic-number nuclides**: Nuclides $^4\text{He}$, $^{16}\text{O}$, $^{40}\text{Ca}$, $^{48}\text{Ca}$, and $^{208}\text{Pb}$ have magic numbers of protons and magic number of neutrons.

### Effect of Paring Nucleons

<table>
<thead>
<tr>
<th>$Z$</th>
<th>$N$</th>
<th>No. of stable nuclides</th>
</tr>
</thead>
<tbody>
<tr>
<td>even even</td>
<td>166</td>
<td></td>
</tr>
<tr>
<td>even odd</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>odd even</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>odd odd</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
**Pairing of nucleons:** More than half (59%) of stable nuclides have even numbers of protons and neutrons. This fact suggests that pairing of protons and neutrons contributes to the stability of nuclides. Since nucleons have \( \frac{1}{2} \) spin, they obey Pauli's exclusion principle by allowing two protons or neutrons each with opposite spin to occupy a quantum state (if they are nucleons in a nucleus). There is a preference for having pairs of protons or neutrons, and it is known as pairing of nucleons.

The effect of pairing also affects the abundance of the isotopes in elements, as well as the abundance of a nuclide on a planet, galactic or universal scale. Nucleon pairing also affects the decay of unstable nuclides.

**Abundance of elements**

- The abundance of an element or nuclide is its amount in a system. Elemental abundances of stars and galaxies can be determined from X-ray spectra in space explorations.
- The sun has 99.9% of the mass of the solar system. Hydrogen atoms contribute 72%, and helium 4He 26% to all atoms in the Sun.
- Taking as a whole, the most abundant element of the planet Earth is iron, which is the major component of the earth (molten) core. Additional evidence comes from the many iron meteorites, which are considered debris from outer space. However, the most abundant element of the Earth crust is oxygen in terms of number of atoms, but silicon is the most abundant element by mass.

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