Separation of isotopes

By

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Isotopes in general

- Atoms of the same element with different numbers of neutrons are called isotopes.
- Most common isotope of hydrogen has no neutrons at all.
- The second isotope of hydrogen has one neutron – deuterium.
- The third isotope has two neutrons - tritium.

Hydrogen  Deuterium  Tritium
Isotopic distribution of silicon:

The distribution of the three different silicon isotopes in the nature is:

\[
\begin{align*}
{^{28}\text{Si}} & \approx 92 \% \\
{^{29}\text{Si}} & \approx 5 \% \\
{^{30}\text{Si}} & \approx 3 \%
\end{align*}
\]

This isotopic distribution is also seen in end products like silicon-chips.
Different isotope separation techniques:

- Diffusion based
- Membrane based
- Distillation
- Chemical exchange
- Electrolysis
- Electromagnetic
- Centrifugation
- Separation nozzle
- Selective excitation by laser
- Ion-mobility
- Chromatography

Light elements and large scale
Heavy elements and large scale
Separation Nomenclature

• Isotope separation, enrichment & depletion are concepts used when the concentration of a specific isotope is altered from its natural occurrence.

• The enrichment factor (beta) is a measure of the separation of isotopes:
  - Beta = 1  No separation took place
  - Beta > 1  Indicates enrichment
  - Beta < 1  Indicates depletion

• The cut (theta) is a measure of the amount of feed that ends up in the product stream.

• The beta and the cut are the determining factors defining the size and cost of a plant.
Separating Unit, Stage and Cascade

- **Separating Unit** is the smallest element of a plant that effects separation – single centrifuge, ASP single stationary wall pipe

- A **Stage** is a group of parallel-connected separating units that is fed the same composition and produces product streams with the same composition

- Stages are connected in series until the desired separation between product and waste is achieved. This is known as a **Cascade**
Cascade Enrichment

- Separating Element

- Simple Cascade

- Recycle Cascade
4-up 1-down Cascade

\[
j = 1, \ldots, n
\]
Separation Nomenclature, continue

- **Separative Working Unit (SWU)** is the amount of separation work done by a cascade to obtain one unit of product of the desired enrichment.

- The **specific energy consumption** ($E/\delta u$) is the amount of energy needed to produce one SWU. For instance if the cost of electricity is $0.03 per kWh, then for a $E/\delta u=1000$ the electricity cost would be $30 per SWU.
Laser Isotope Separation

- When different isotopes have slightly different levels of excitation
- Radiation of the right frequency must be available
- The excited species must have the ability to be easily separated
- The selectivity for the desired isotope must be good
- Still too complex to be used industrially

Laser-based isotope enrichment of Carbon 12/13:
Different separation techniques based on centrifugation:

**Rosegard Vortex Extraction**

October, 1976

Enrichment: 1.056 (Argon)

Cut: 6-8%
March, 1976:
Enrichment: 1.023
Cut: 50%
UCOR Vortex Process

- Enrichment is achieved under pressurized conditions by centrifugal means in a stationary-wall centrifuge

1975 – 1990:
Enrichment: 1.03
Cut: 5%
NO PATENT
Separation based on chromatographic methods

Theory on diffusion of gaseous species through the chromatographic column:

**Fick’s 1st law:**
\[ J_x = -D_x \frac{\partial c}{\partial x} \]
, the flux (J) along the direction x is proportional to the concentration (c) gradient. D is the diffusion coefficient.

**Fick’s 2nd law:**
\[ \frac{\partial c}{\partial t} = D_x \frac{\partial^2 c}{\partial x^2} \]
, when D is constant.

The compound containing 3 isotopes is released at time t=0.

Distribution at t=1

Distribution at t=4
Results: Chemical separation

Comment: Silan pulse
File Name: SILAN2.D
Analysis date: 14 Nov 2001
Analysis time: 9:58 am
Abundance:
TIC: 4.601e+6

Retention time (min)

TIC
Ar
SiH₄

ISOSILICON
Results: Chemical separation

Conclusion:
- The retention of silane is not of kinetic nature since argon is heavier than silane and should therefore move slower.
- The retention must be due to molecular interactions between the porous material in the column and silane.
Results: Mass separation – selectivity coefficient

\[ \alpha \frac{29}{33} = \frac{I_{29}}{I_{33}}, \quad \alpha \text{ is the selectivity coefficient} \]

\[ I_i = \frac{\int_{t_1}^{t_2} c_i(L, t) dt}{\int_{0}^{\infty} c_i(L, t) dt} \]

\( \alpha \) is calculated from the ratio of the areas under the flanks of the mass distribution
**Results: Mass separation – selectivity**

Separation factors in the order of 1.10 is possible, but on the expense of the yield.