Separation of isotopes

By

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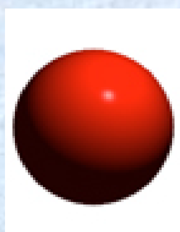
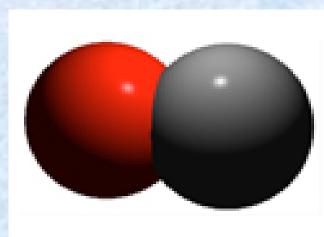
Isotopes in general

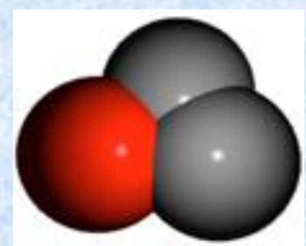
- Atoms of the same element with *different numbers of neutrons* are called isotopes
- Most common isotope of hydrogen has no neutrons at all
- The second isotope of hydrogen has one neutron – deuterium
- The third isotope has two neutrons - tritium



Hydrogen



Deuterium

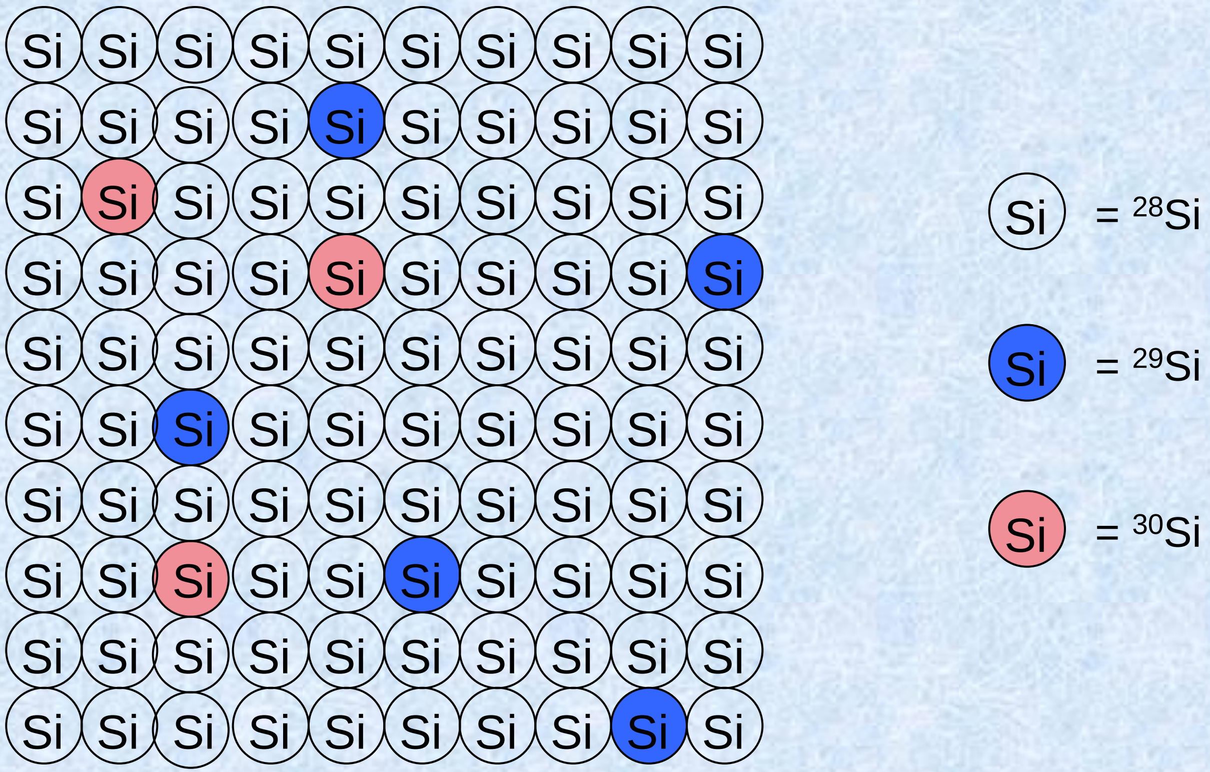


Tritium

Isotopic distribution of silicon:

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

^{28}Si ≈ 92 % ^{29}Si ≈ 5 % ^{30} Si ≈ 3 %



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

Distillation, Chemical exchange → Light elements and large scale

Centrifugation → 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

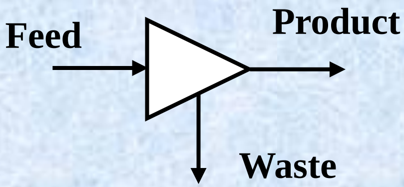
- *Separating Unit* is the smallest element of a plant that effects separation – single centrifuge, ASP single stationary wall pipe

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

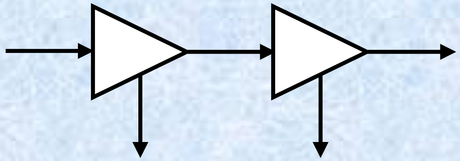
- Stages are connected in series until the desired separation between product and waste is achieved. This is known as a *Cascade*

Cascade Enrichment

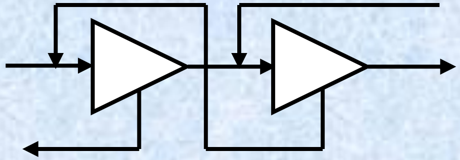
- Separating Element



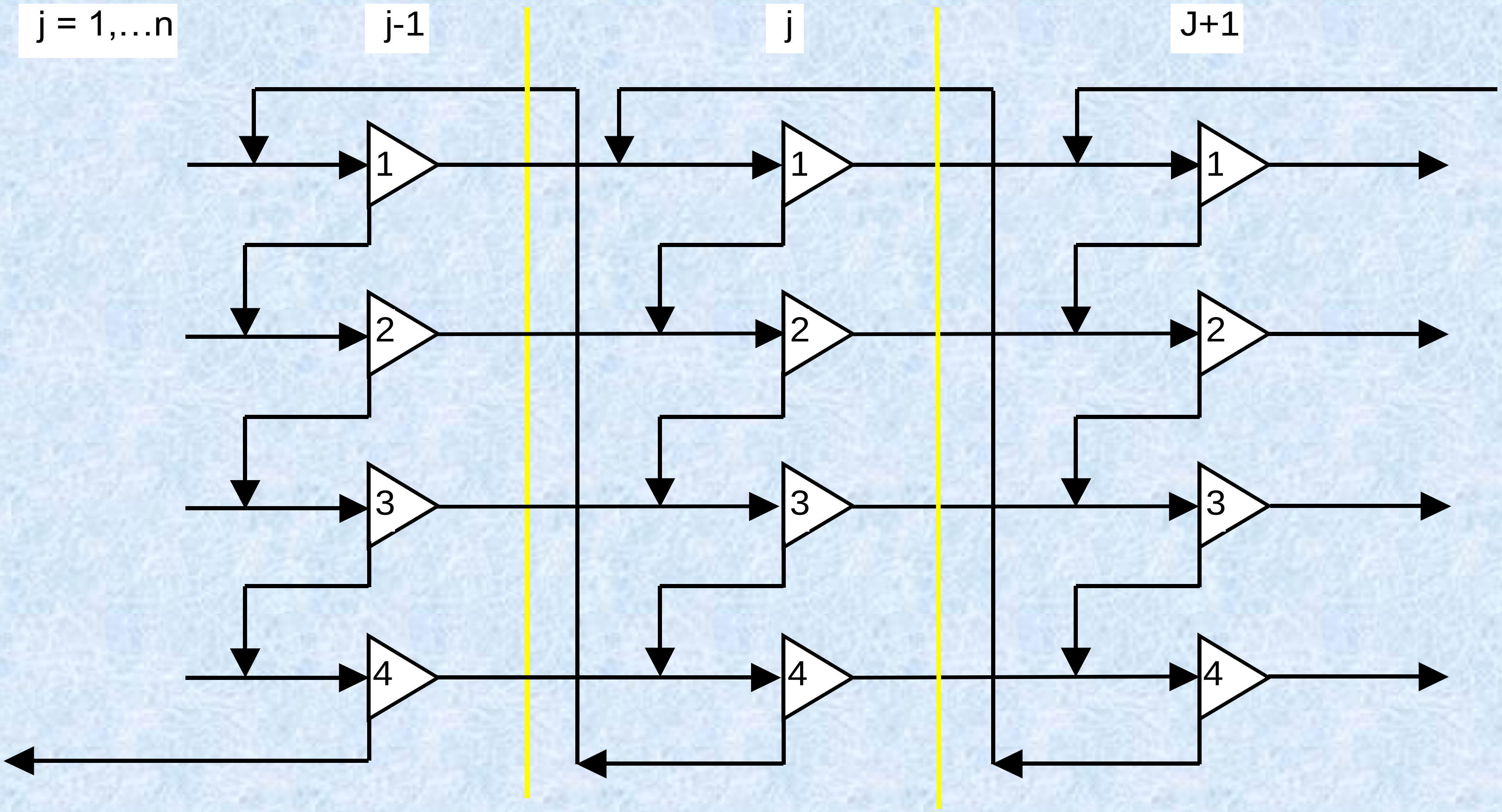
- Simple Cascade



- Recycle Cascade



4-up 1-down Cascade



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 to complex to be used industrially

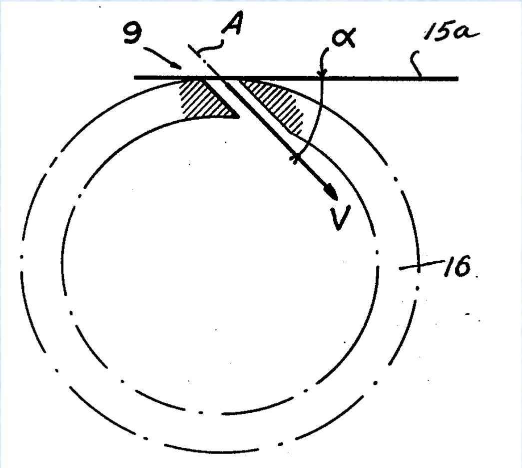
Laser-based isotope enrichment of Carbon 12/13:

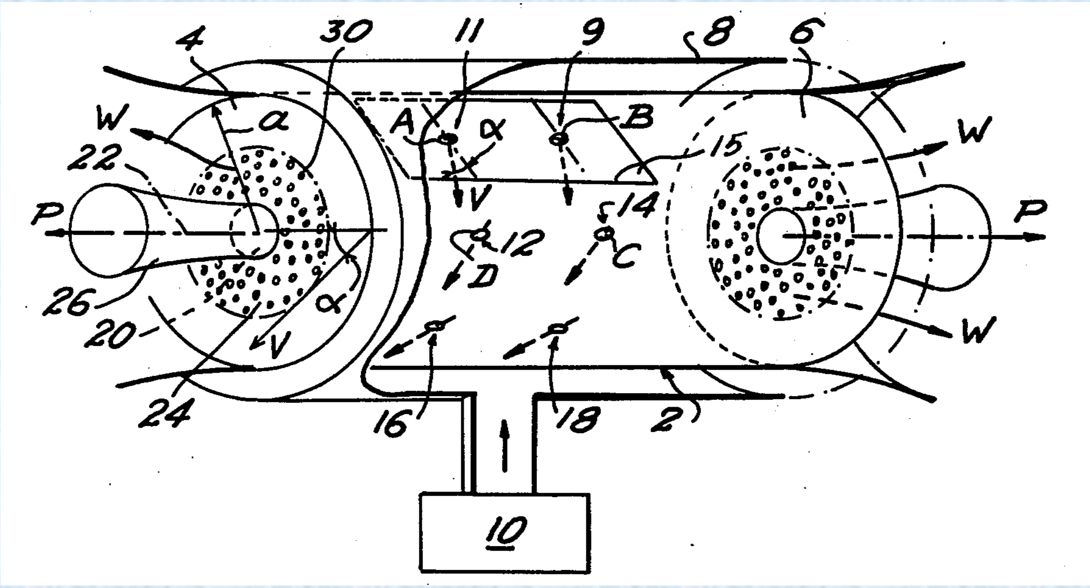
Different separation techniques based on centrifugation:

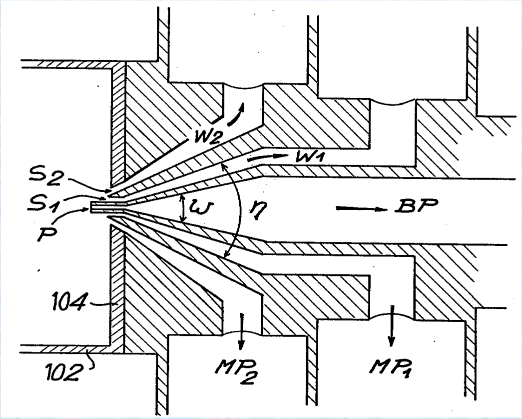
Rosegard Vortex Extraction

October, 1976

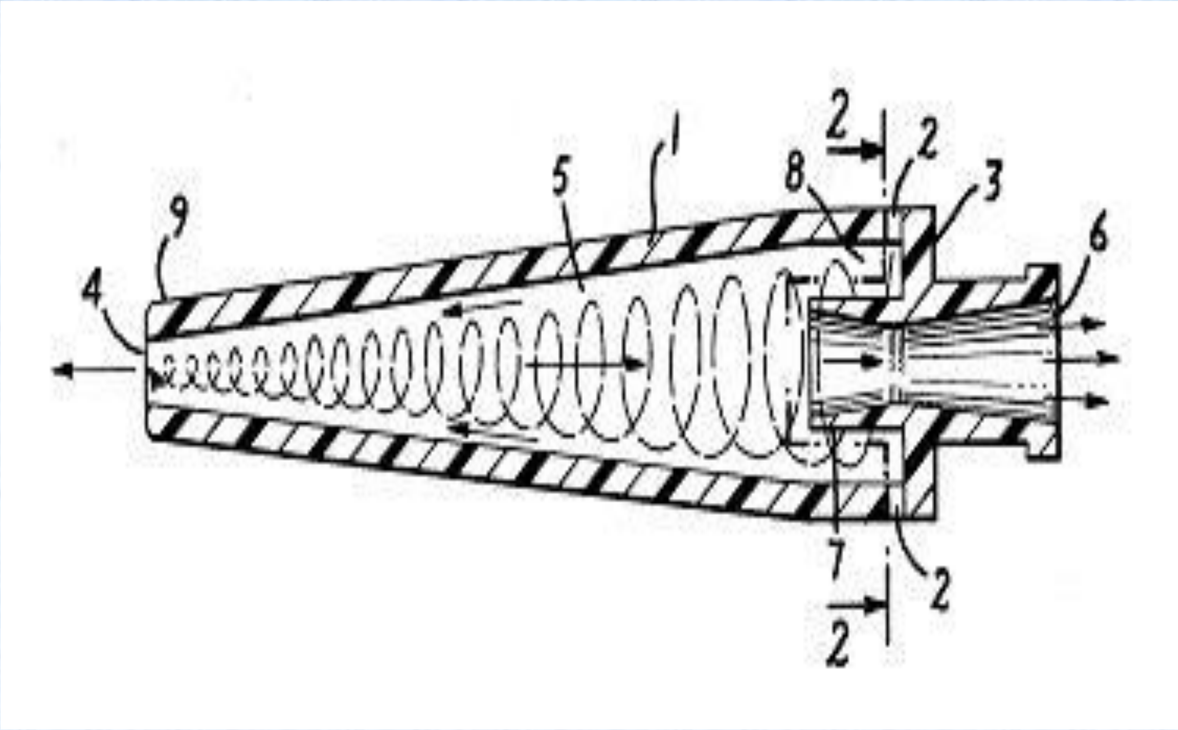
Enrichment:	1.056 (Argon)
Cut:	6-8%







Wikdahl Vortex Separation



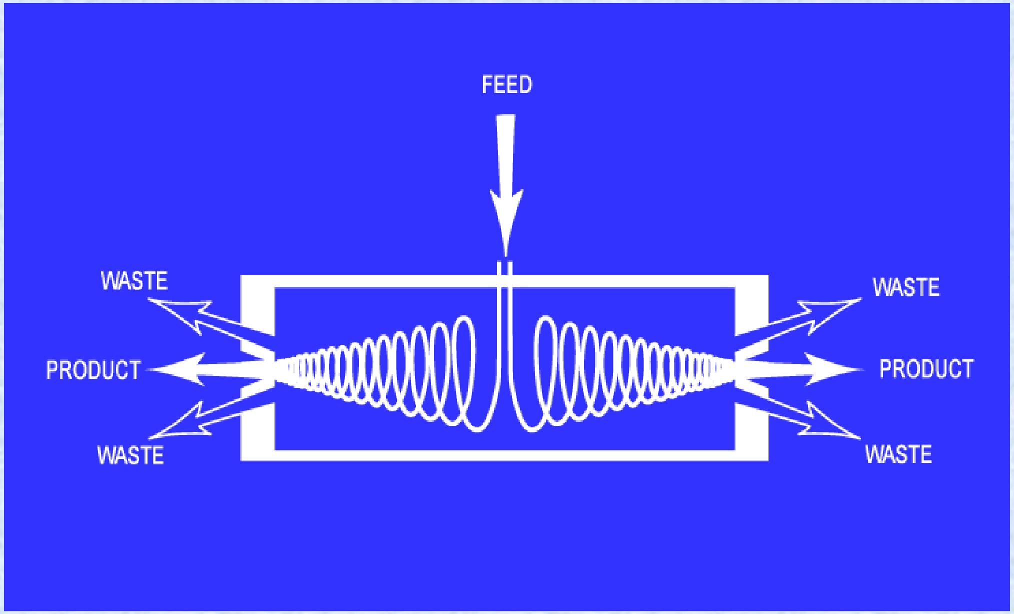
March, 1976:

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

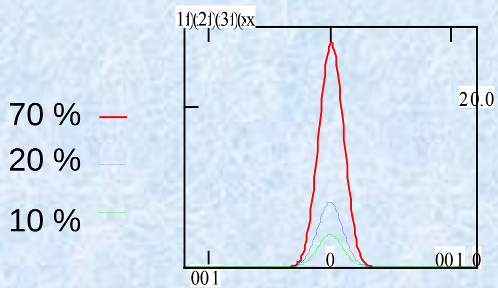
Separation based on chromatographic methods

<u>Theory on diffusion of gaseous species through the chromatographic column:</u>

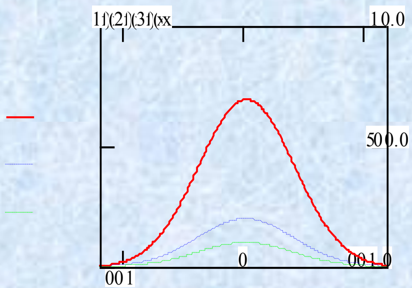
Fick's 1st law: $J_x = -D_x \dfrac{\partial c}{\partial x}$, the flux (J) along the direction x is proportional to the concentration (c) gradient. D is the diffusion coefficient.

Fick's 2nd law: $\dfrac{\partial c}{\partial t} = D_x \dfrac{\partial^2 c}{\partial x^2}$, when D is constant.

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



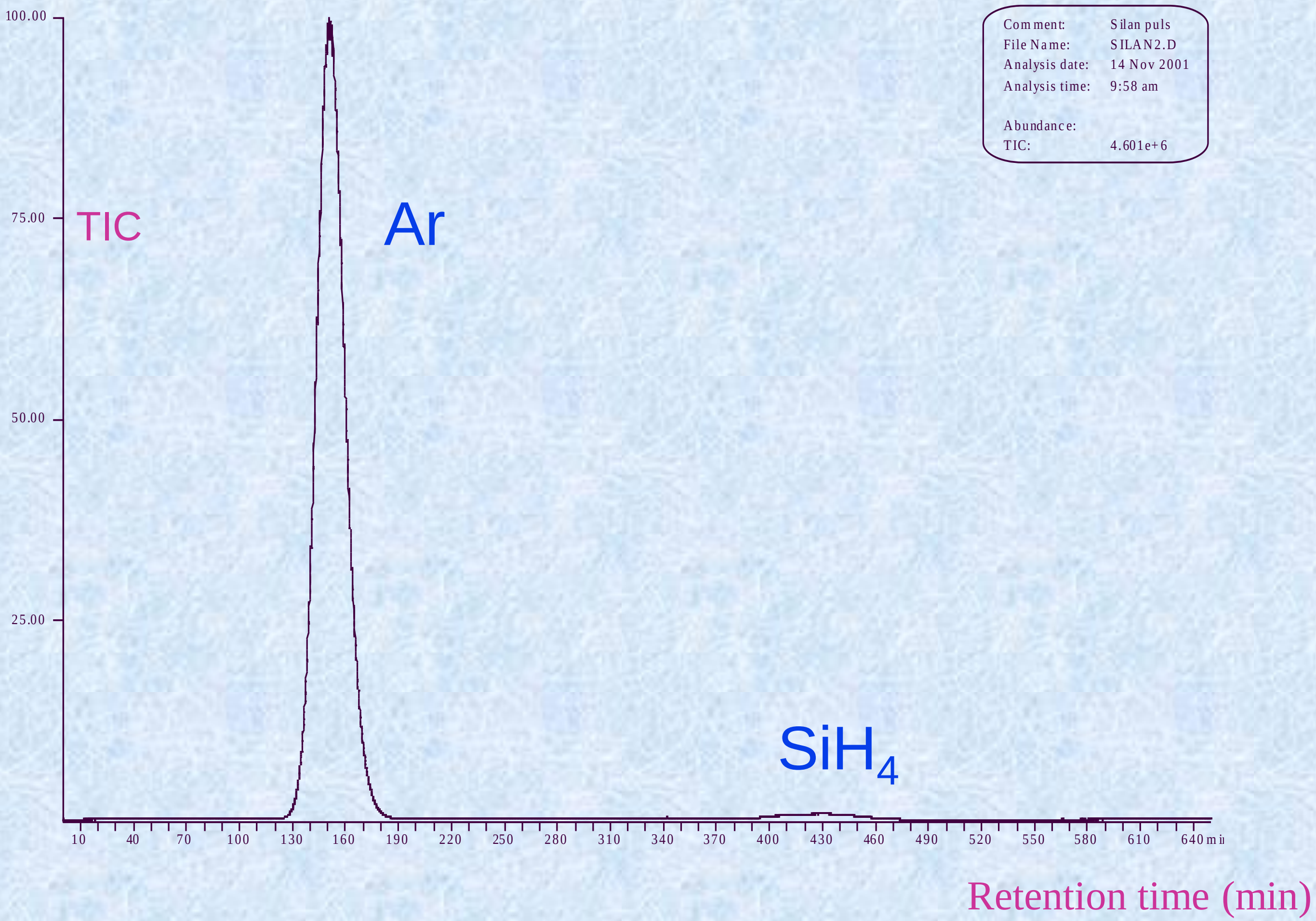
Distribution
at t=1



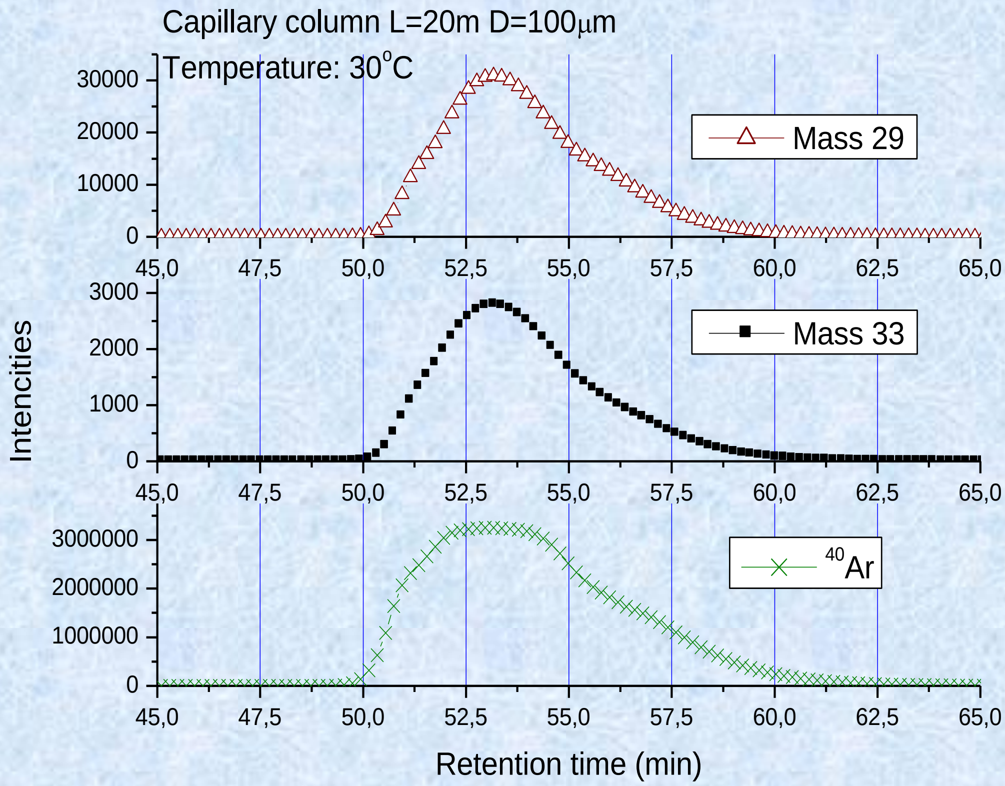
Distribution
at t=4

ISOSILICON

Results: Chemical separation



Results: Chemical separation



Conclusion:

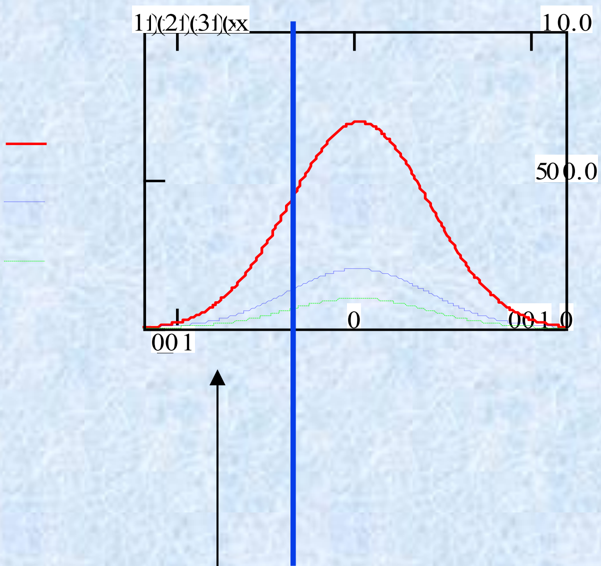
- *The retention of silane is not of kinetic nature since argon is heavier than silane and should therefore move slower.*
- *The retention must be due to molecular interactions between the porous material in the column and silane.*

Results: Mass separation – selectivity coefficient

$$\alpha_{33}^{29} = \frac{I_{29}}{I_{33}}$$

, α is the selectivity coefficient

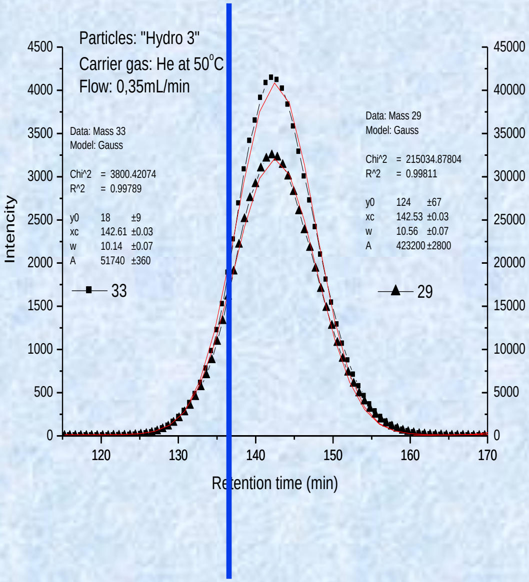
$$I_i = \frac{\int_{t_1}^{t_2} c_i(L,t)\,dt}{\int_{0}^{\infty} c_i(L,t)\,dt}$$

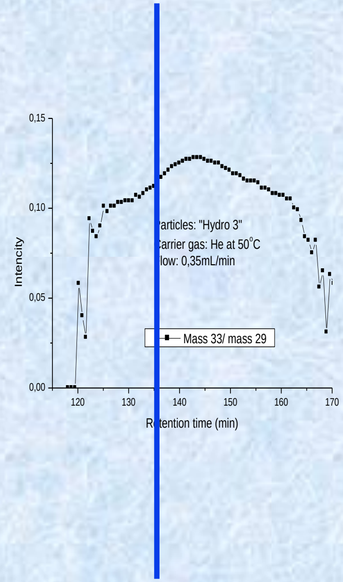


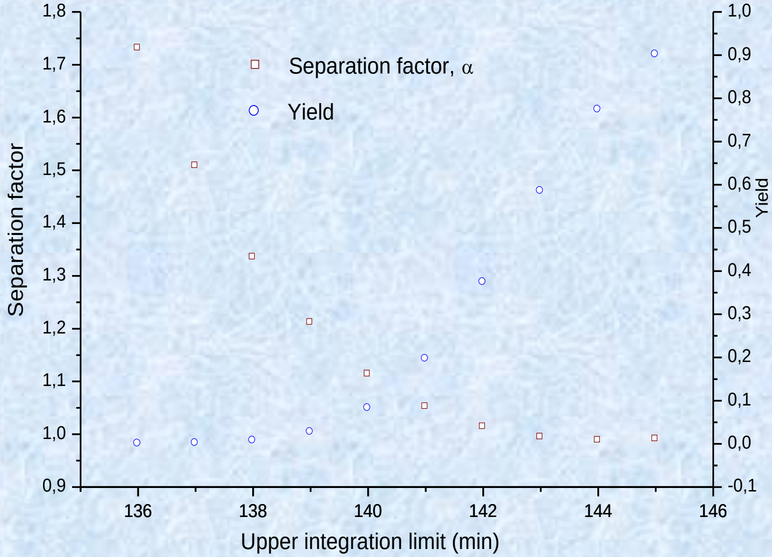
α is calculated from the ratio of the

areas under the flanks of the mass distribution

<u>Results: Mass separation – selectivity</u>







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