NIZHNY NOVGOROD STATE TECHNICAL UNIVERSITY
N.A. R.E. ALEKSEEV

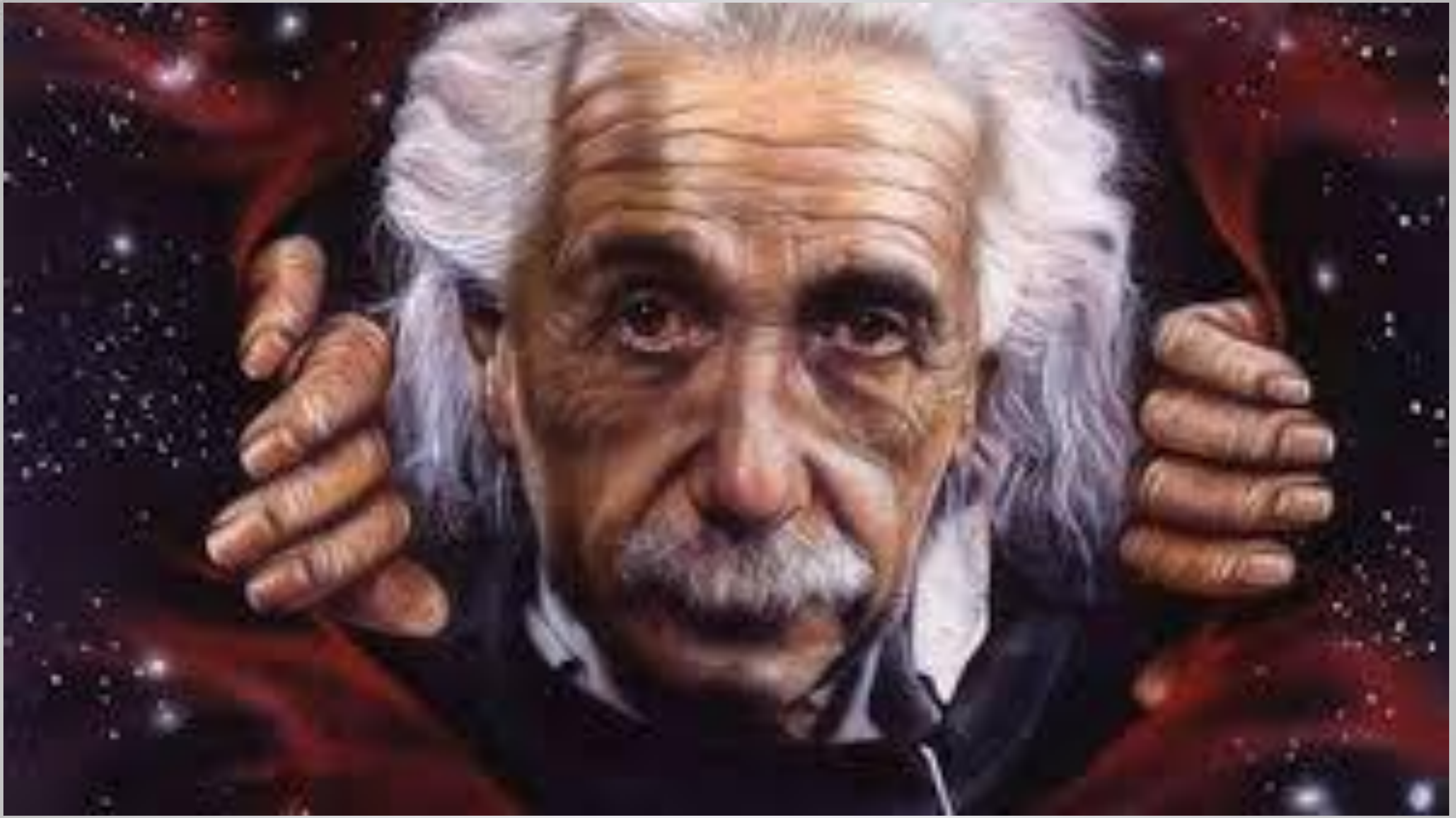
Химики без границ

Prof. Ilya V. Vorotyntsev

Nanotechnology and Biotechnology Department

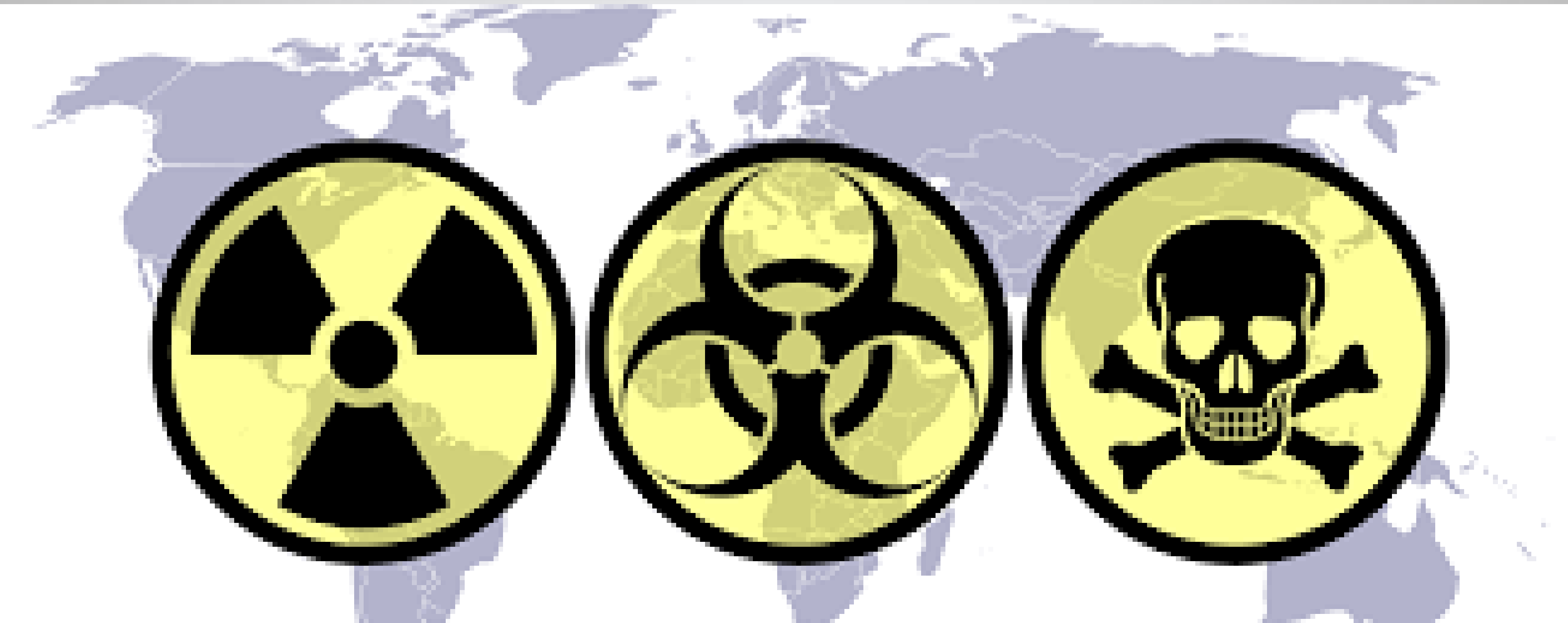
LMCP

Laboratory of Membrane and Catalytic Processes



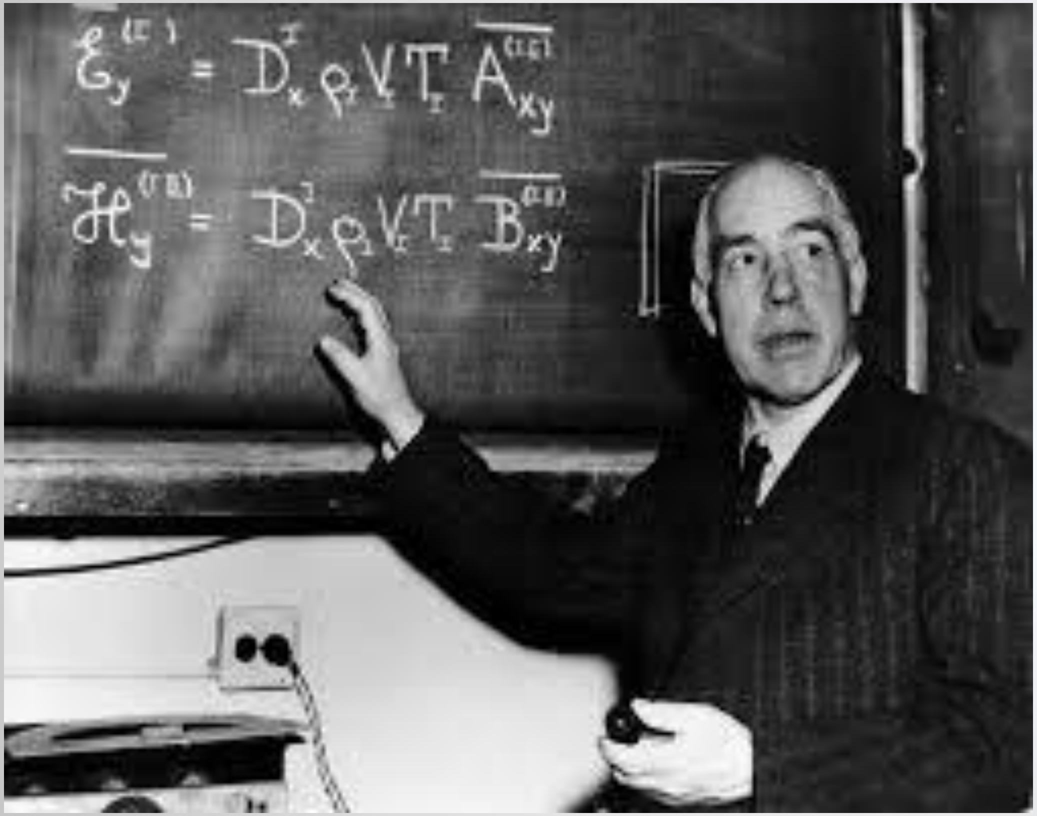
Окружающий Мир это дружественная или враждебная среда?

Почему мы боимся химии?



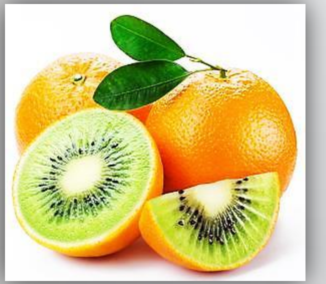
Почему мы боимся химии?

Нильс БОР

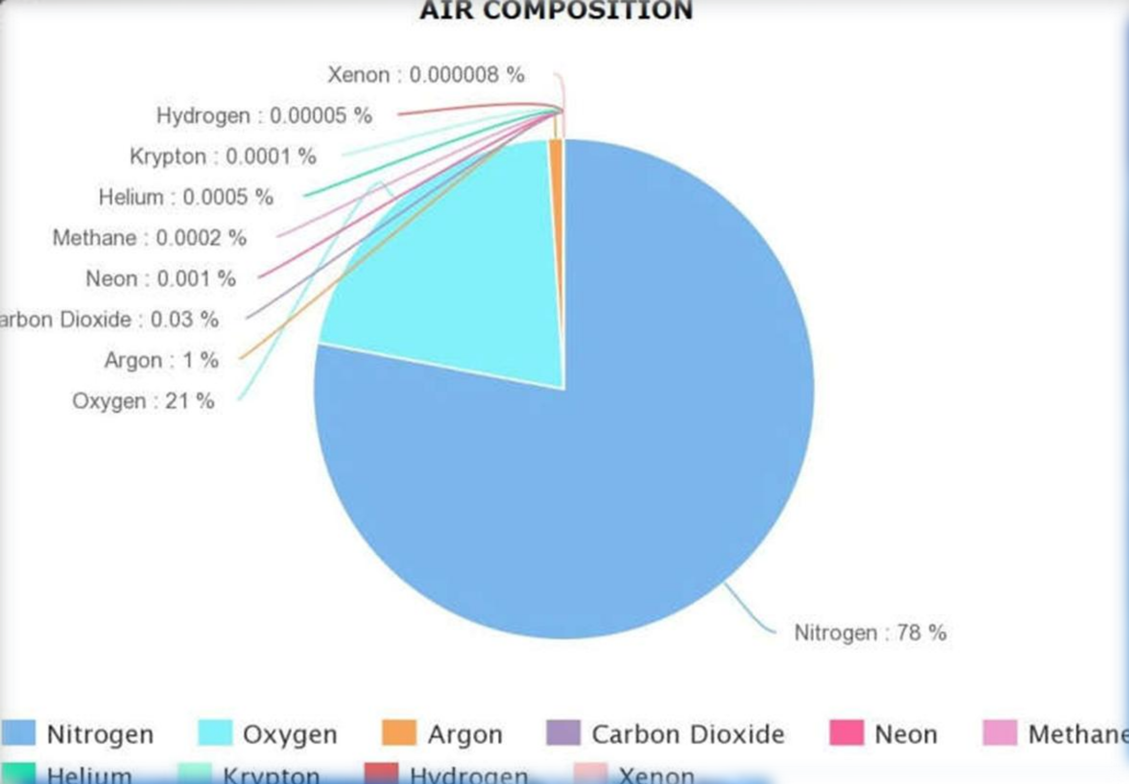


- На свете есть столь серьезные вещи, что говорить о них можно только шутя…

Химия вокруг нас…

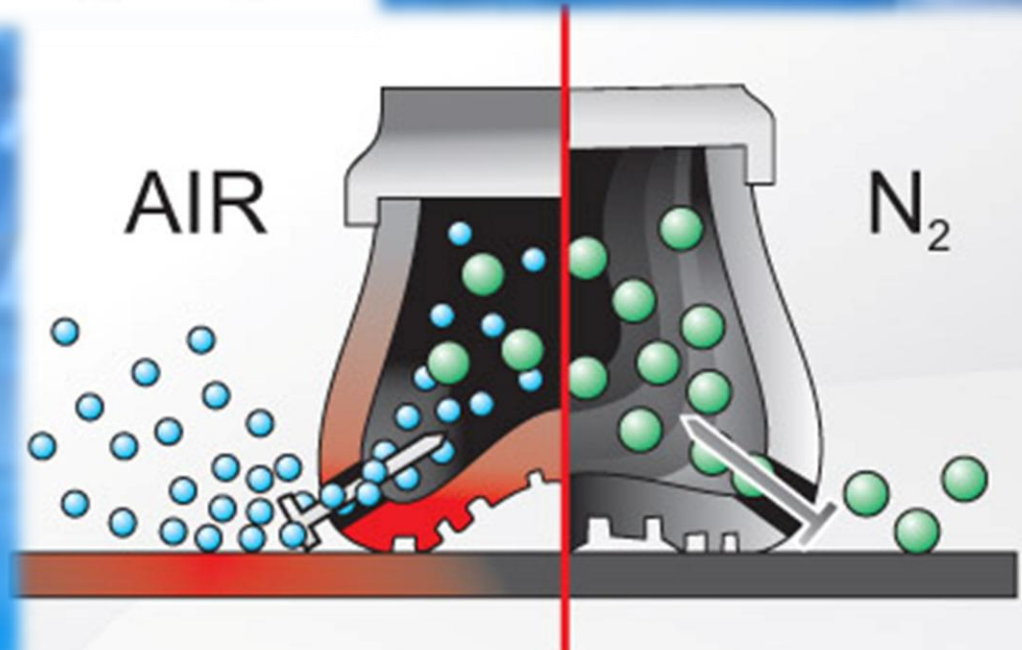


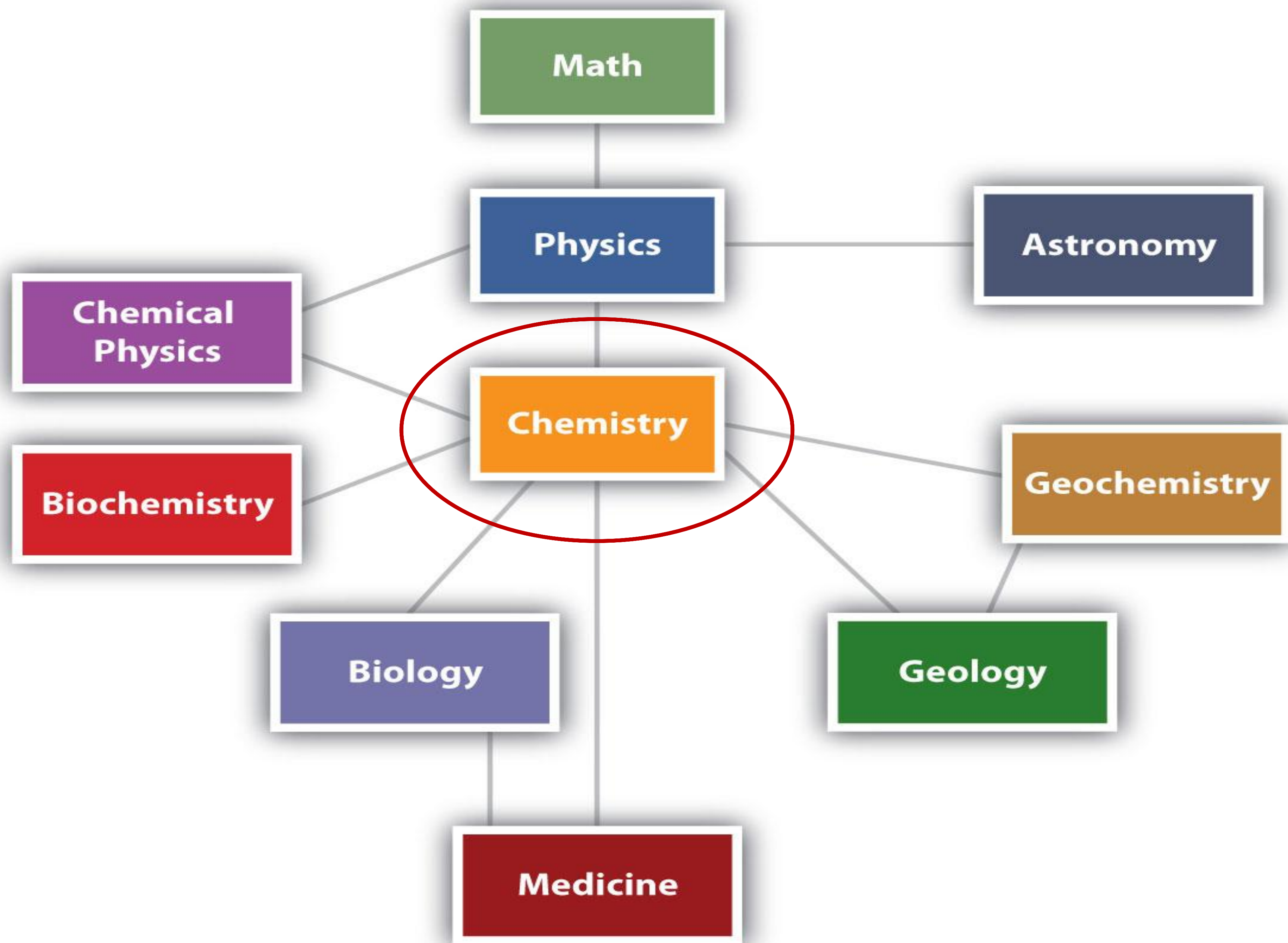
Всё, что нас окружает – это химия!

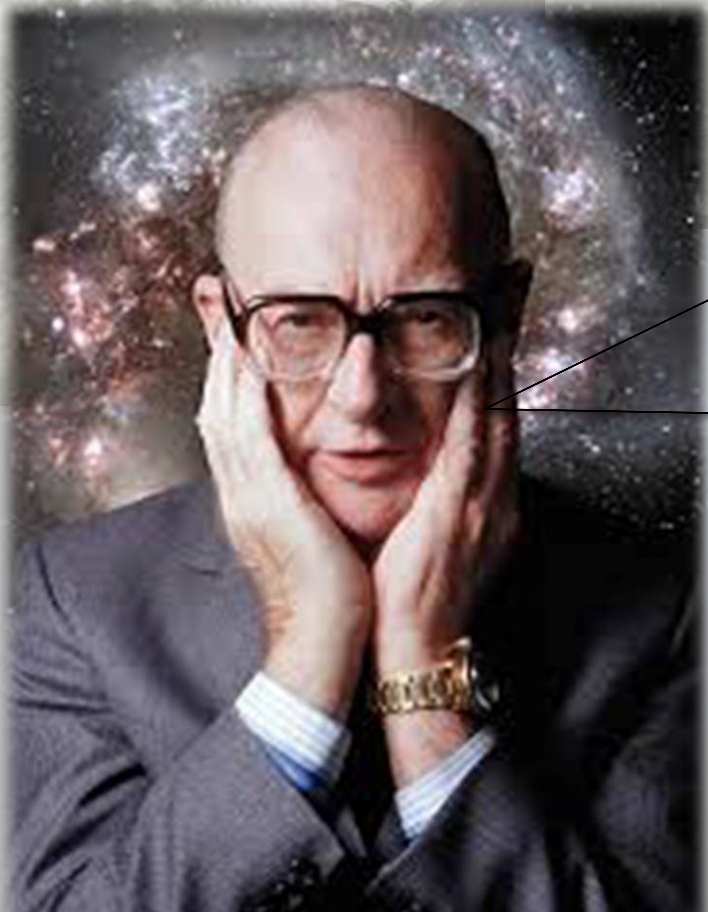

AIR COMPOSITION
Xenon : 0.000008 %
Hydrogen : 0.00005 %
Krypton : 0.0001 %
Helium : 0.0005 %
Methane : 0.0002 %
Neon : 0.001 %
arbon Dioxide : 0.03 %
Argon : 1 %
Oxygen : 21 %
Nitrogen : 78 %
Nitrogen
Oxygen
Argon
Carbon Dioxide
Neon
Methane
Helium
Krypton
Hydrogen
Xenon


21%
O_2


78%
N


AIR
N_2


Math
Physics
Astronomy
Chemical Physics
Chemistry
Geochemistry
Biochemistry
Biology
Geology
Medicine



Сэр Артур Чарльз КЛАРК

Any sufficiently advanced technology is indistinguishable from magic*

* «Любая достаточно развитая технология неотличима от волшебства»

Электроника – неотъемлемая часть нашей жизни!

Электроника – «мозг и нервная система» высокотехнологичных изделий всех отраслей мировой индустрии!

Повседневная химия

30 мг

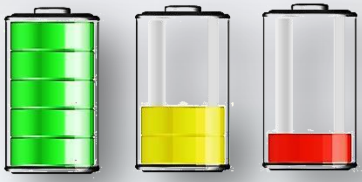
79
Au
Золото
195.966

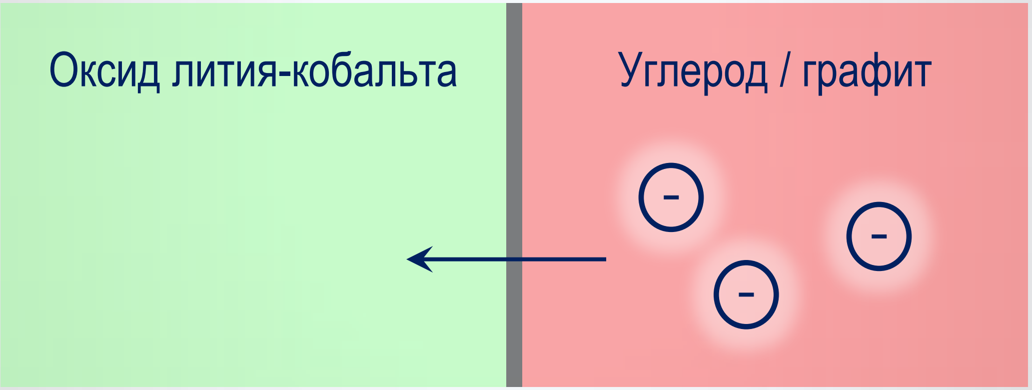
300 мг

47
Ag
Серебро
107.868

Сайт кафедры «Нанотехнологии и биотехнологии»
http://www.nntu.ru/nbt

Повседневная химия





КАТОД + **АНОД -**

Сайт кафедры «Нанотехнологии и биотехнологии»
http://www.nntu.ru/nbt

Повседневная химия

59
Pr
Празеодим
140.908

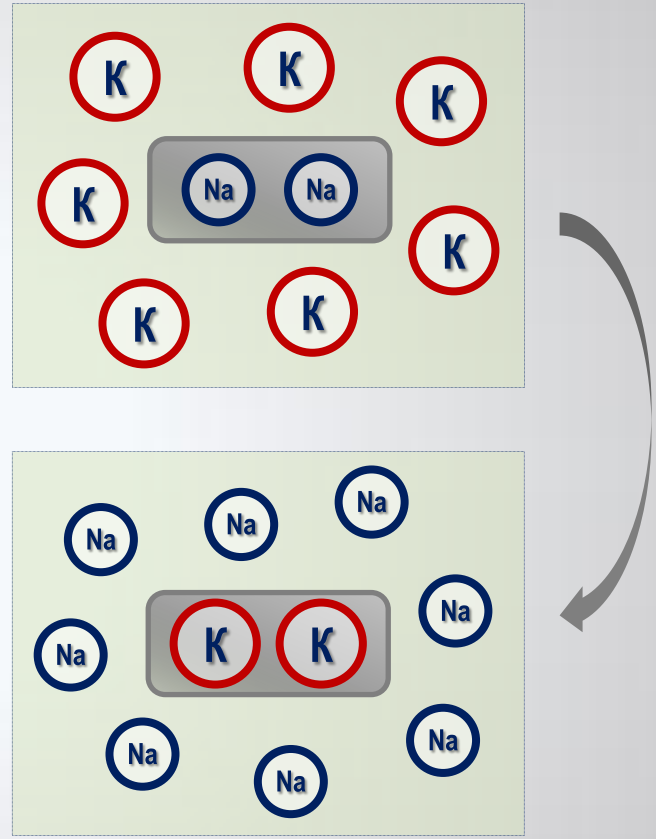
65
Tb
Тербий
158.925

39
Y
Иттрий
88.906

64
Gd
Гадолиний
157.253

Сайт кафедры «Нанотехнологии и биотехнологии»
http://www.nntu.ru/nbt

Повседневная химия



Сайт кафедры «Нанотехнологии и биотехнологии»
http://www.nntu.ru/nbt

Повседневная химия

49
In
Индий
114.818

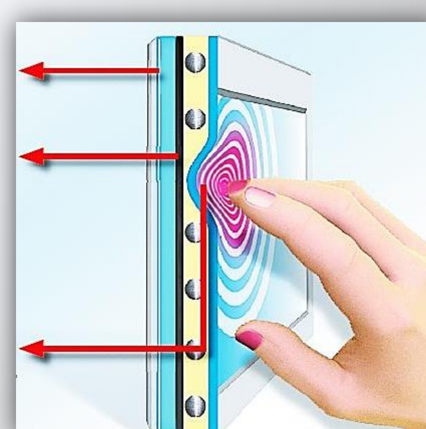
50
Sn
Олово
118.710

8
O
Кислород
15.999

Токопроводящий слой

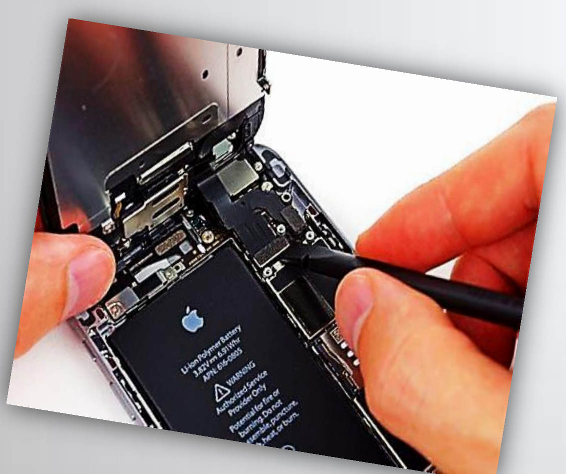
Второй токопроводящий слой на минимальном расстоянии

При прикосновении слои соприкасаются, и возникает слабый ток



Сайт кафедры «Нанотехнологии и биотехнологии»
http://www.nntu.ru/nbt

Повседневная химия

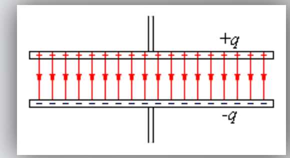


29
Cu
Медь
63.546

→ Металлизация

73
Ta
Тантал
180.948

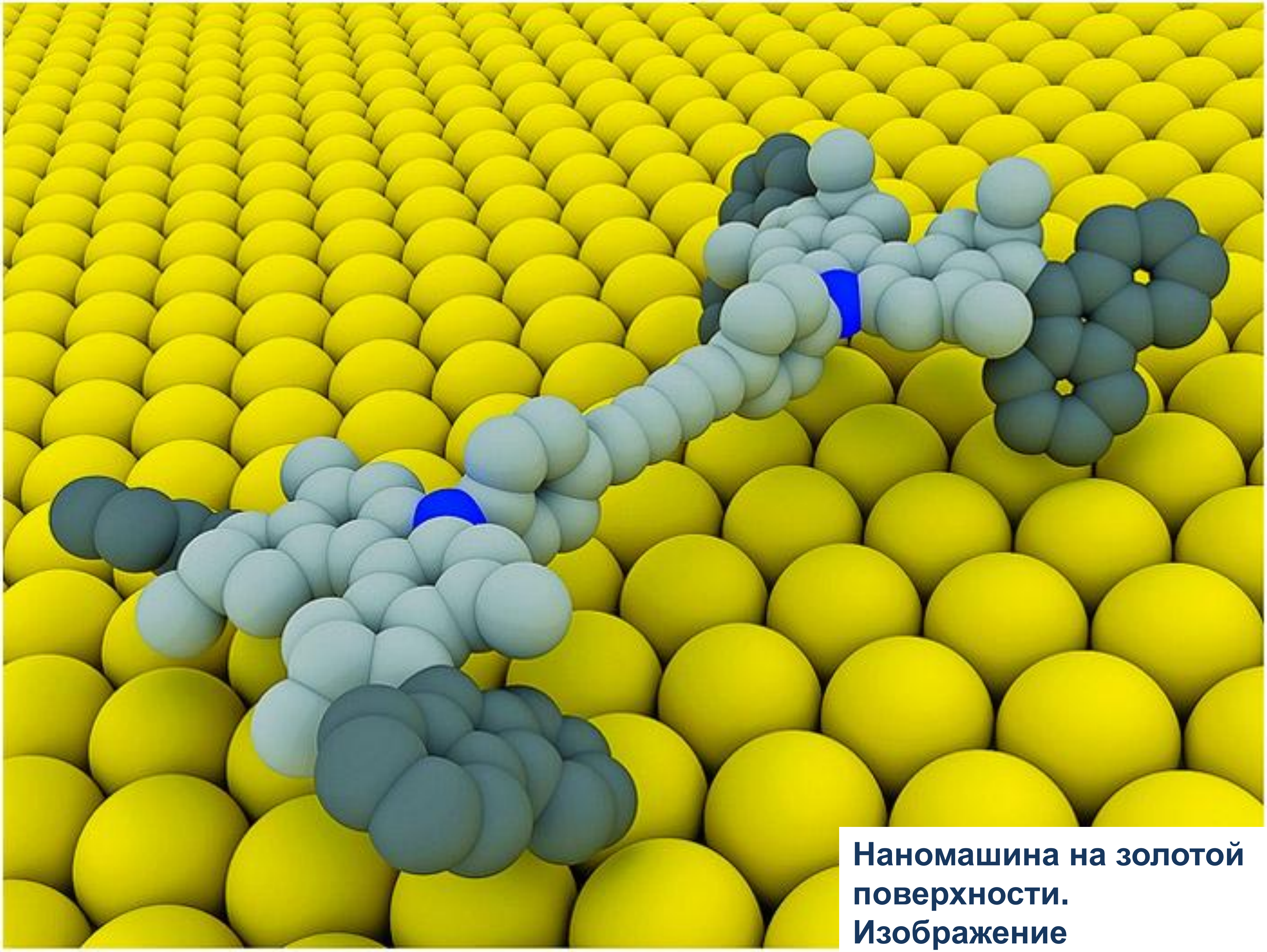
→ Конденсаторы



14
Si
Кремний
28.085

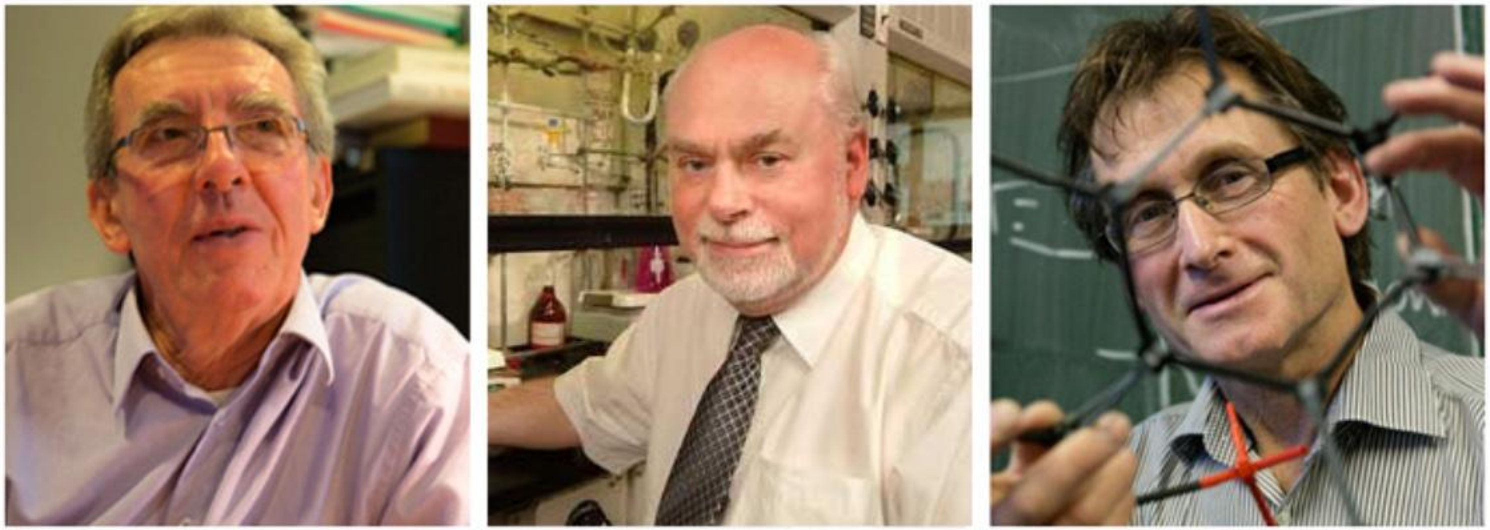
→ Мозг всей системы!

Сайт кафедры «Нанотехнологии и биотехнологии»
http://www.nntu.ru/nbt

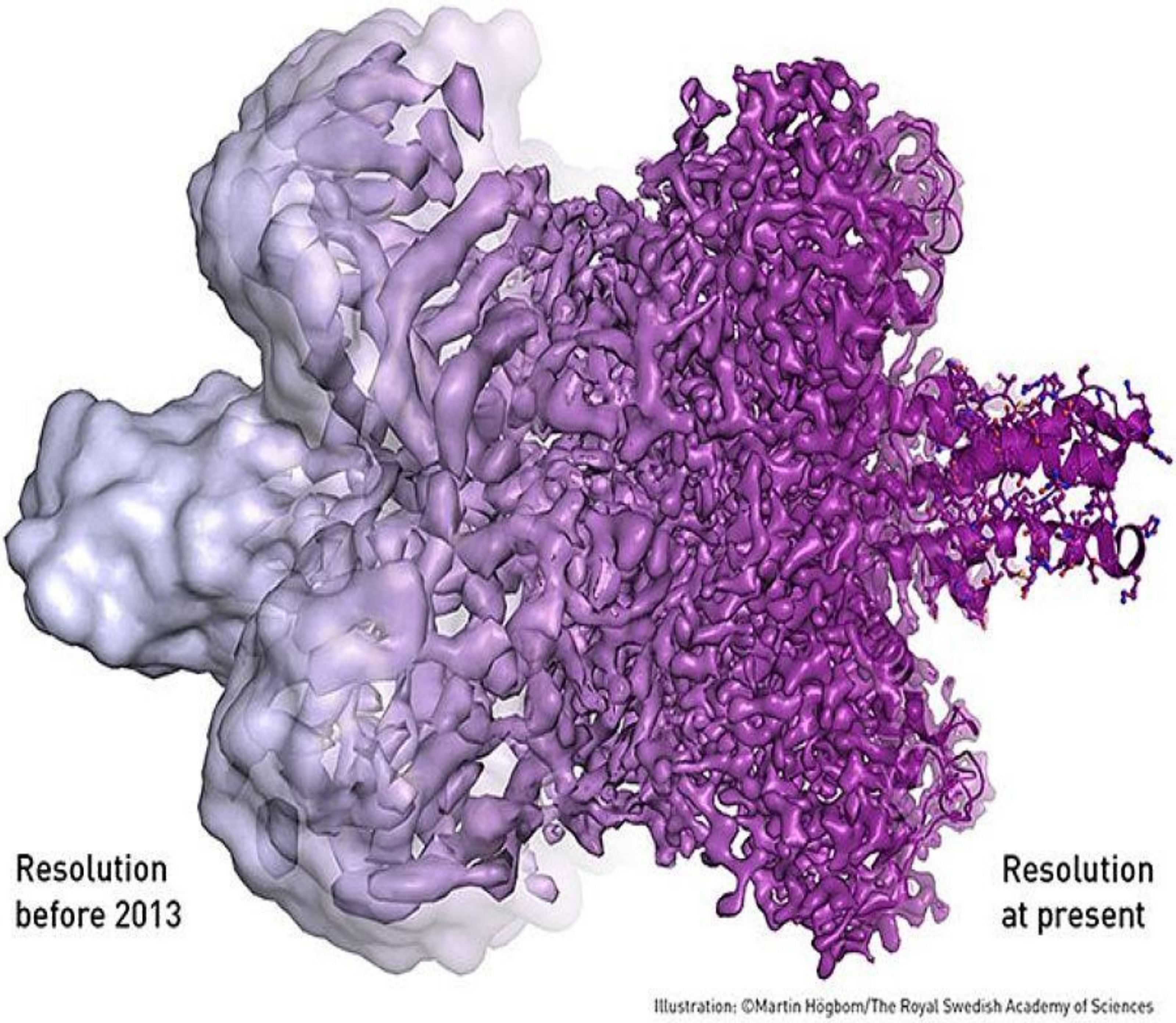


Наномашина на золотой поверхности. Изображение

Nobel Prize 2016



Лауреаты Нобелевской премии по химии 2016 года: Жан-Пьер Соваж (Jean-Pierre Sauvage), Фрейзер Стоддарт (J. Fraser Stoddart), и Бернард Феринга (Bernard L. Feringa). Изображение с сайта cen.acs.org


Resolution
before 2013
Resolution
at present
Illustration: ©Martin Högbom/The Royal Swedish Academy of Sciences

Nobel Prize 2017

Рис. 1. Лауреаты Нобелевской премии по химии 2017 года. *Слева направо:* Жак Дюбоше, Йоахим Франк и Ричард Хендерсон. Фото с сайта sciencenews.org

НЕ НОБЕЛЕВСКИЙ ЛАУРЕАТ



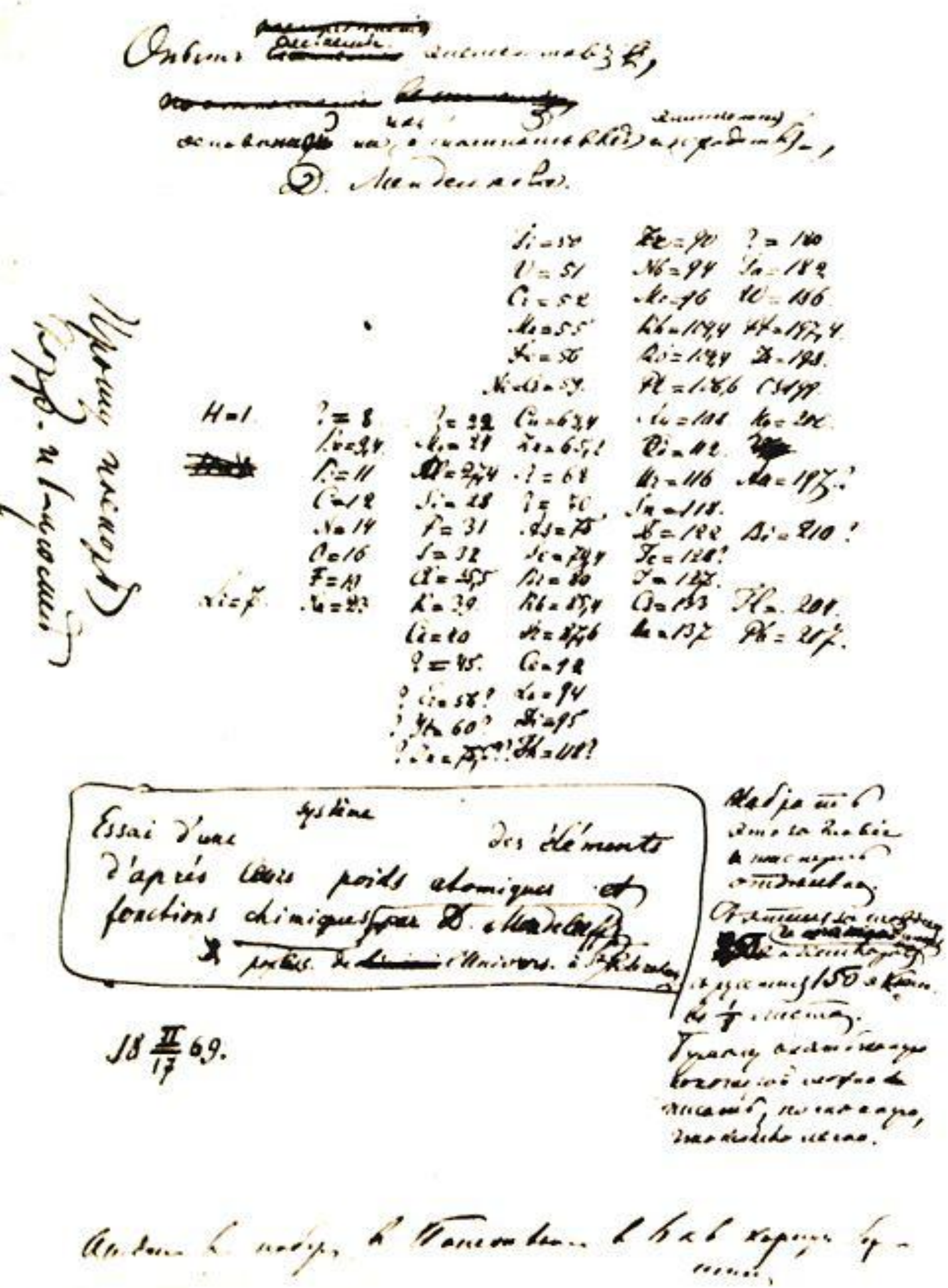
ИМЯ РОССИЯ

ИСТОРИЧЕСКИЙ ВЫБОР 2008

АЛЕКСАНДР НЕВСКИЙ

Общий рейтинг

	всего голосов	место
Александр Невский	524 575	1
П.А. Столыпин	523 766	2
И.В. Сталин	519 071	3
А.С. Пушкин	516 608	4
Петр I	448 857	5
В.И. Ленин	424 283	6
Ф.М. Достоевский	348 634	7
А.В. Суворов	329 028	8
Д.И. Менделеев	306 520	9
Иван IV Грозный	270 570	10
Екатерина II	152 306	11
Александр II	134 622	12



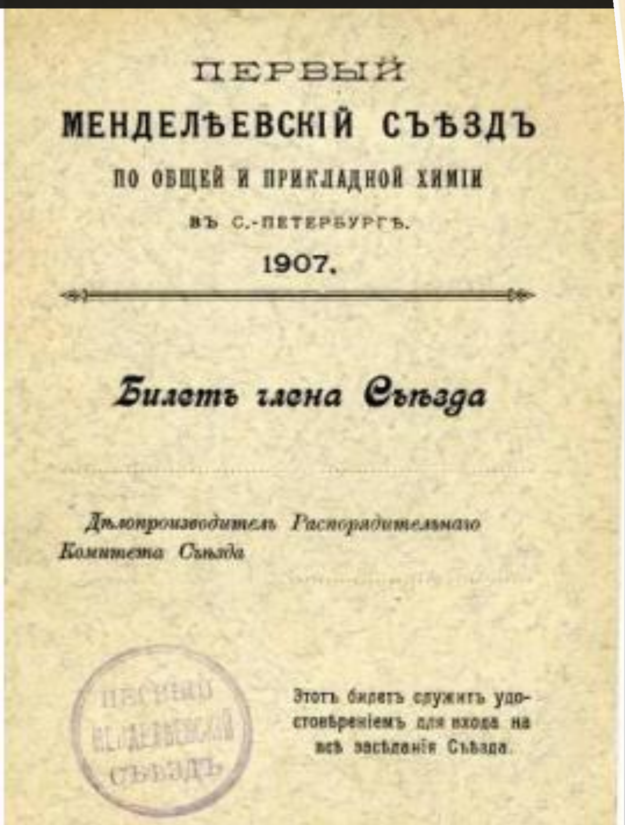
Первый набросок Таблицы…

2019 IYPT

RUSSIAN CHEMICAL SOCIETY n. a. D. I. Mendeleev

January 1868

The first congress of Russian naturalists



ПЕРВЫЙ

МЕНДЕЛѢЕВСКІЙ СЪѢЗДЪ

ПО ОБЩЕЙ И ПРИКЛАДНОЙ ХИМІИ

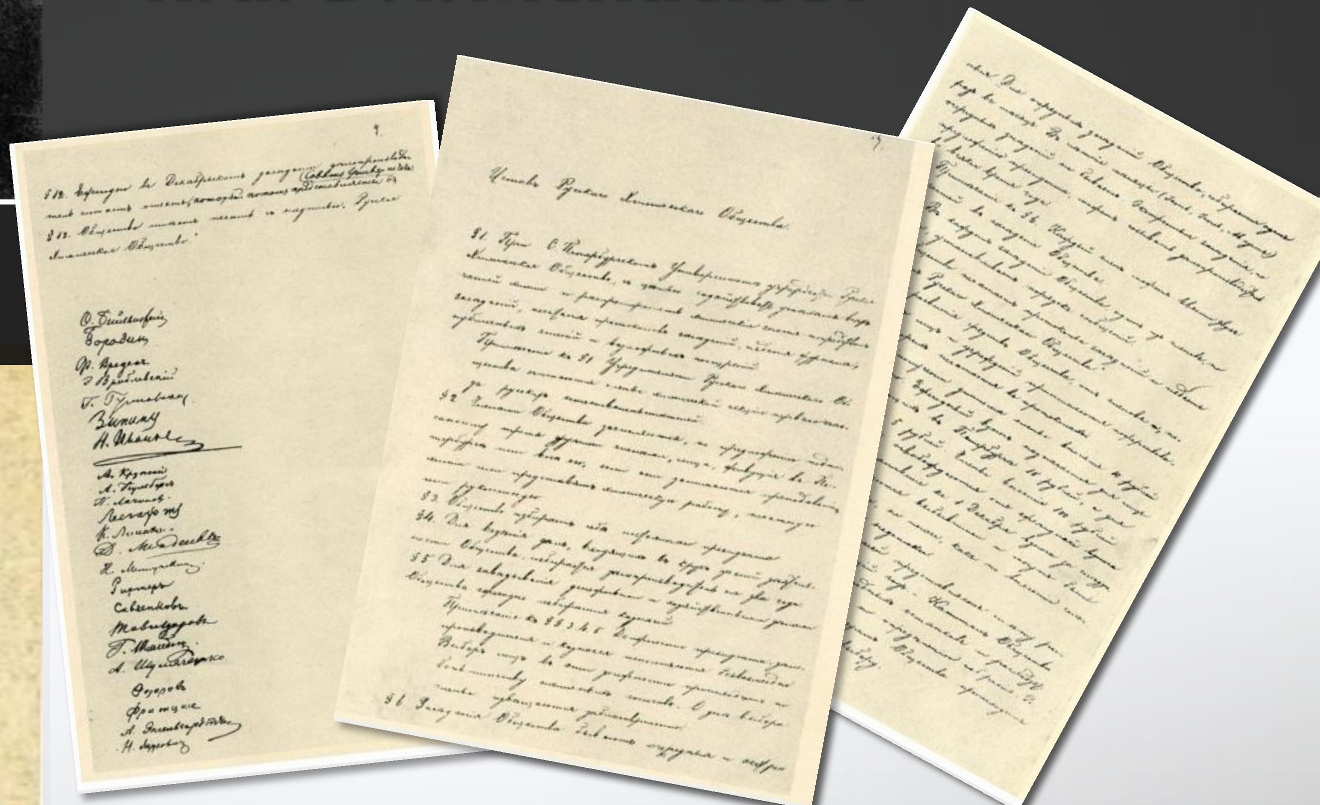
ВЪ С.-ПЕТЕРБУРГѢ.

1907.

Билетъ члена Съѣзда

Дѣлопроизводитель Распорядительнаго Комитета Съѣзда

Этотъ билетъ служитъ удостовѣреніемъ для входа на всѣ засѣданія Съѣзда.



February **1868** - sketch of the main provisions of the Charter

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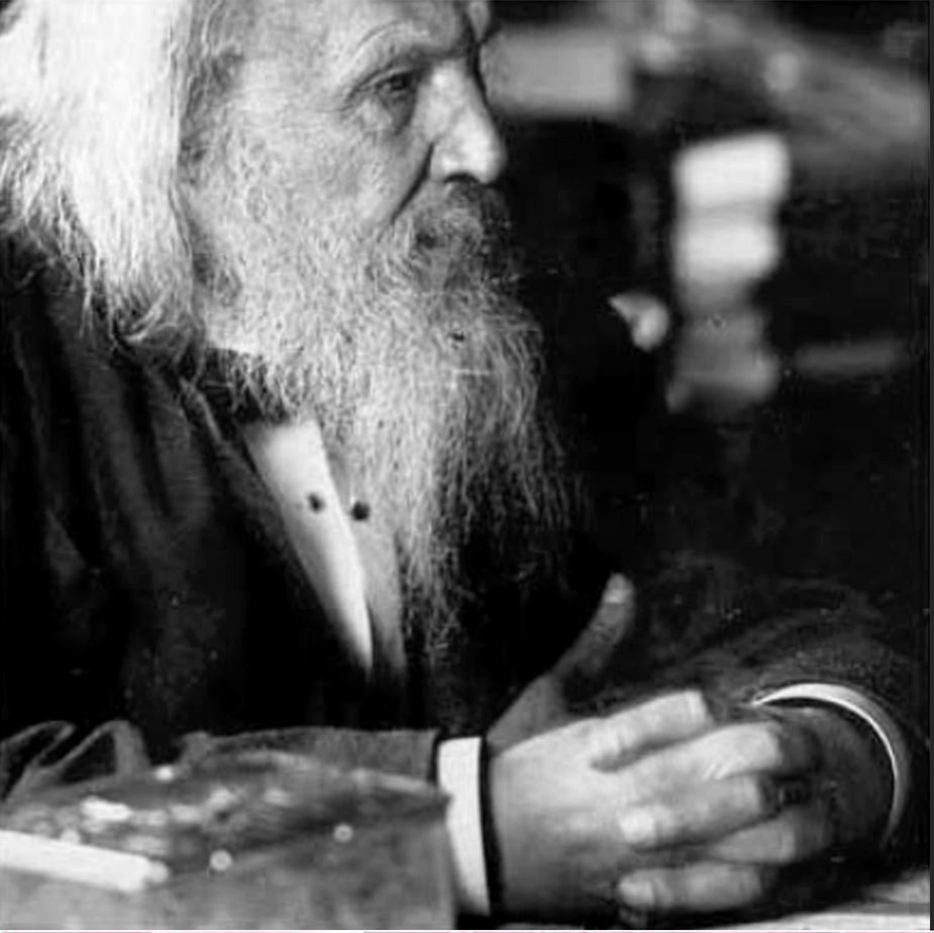
1907 - the first Mendeleev Congress on General and Applied Chemistry

NUMBER OF MEMBERS OF THE RUSSIAN CHEMICAL SOCIETY



YOUTH COMMUNITY

A NEW STAGE OF CHEMICAL SOCIETY n. a. D. I. Mendeleev

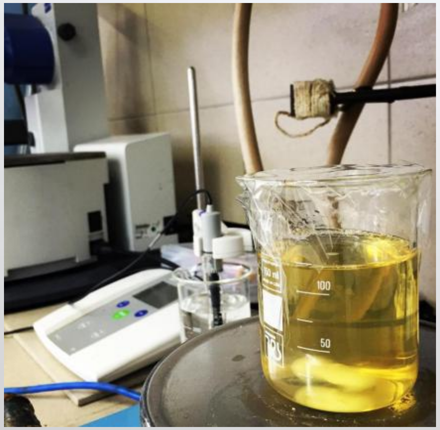

Together with the whole planet!
2019
IYPT
40 000 PARTICIPANTS
FROM 188 COUNTRIES
XIX Всемирный
19th World Festival of
and Students

IYCN

IYCN

WELCOME

Laboratory of membrane and catalytic processes



LMCP

www.lmcp.today

604050, Nizhny Novgorod,
Minina Street, 24

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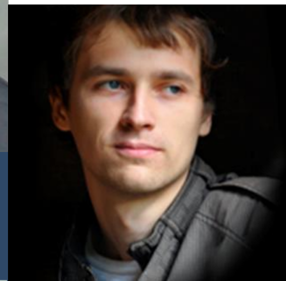
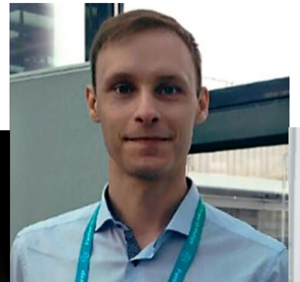
Prof. Ilya V. Vorotyntsev



Anton Petukhov
Chemical Technology

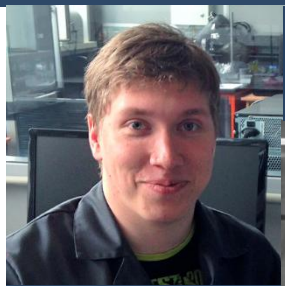


Maxim Trubyanov
Chemical Technology

Andrey Vorotyntsev
Chemistry

Tatyana Sazanova
Chemistry

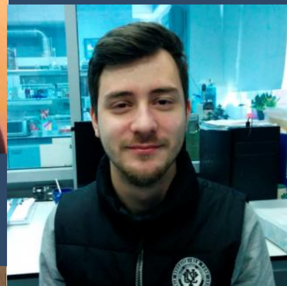
Alsu Akhmetshina
Chemistry



Nail Yanbikov
Chemical Technology

Artem Atlaskin
Chemical Technology

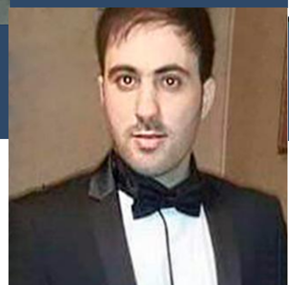
Stanislav Battalov
Chemical Technology



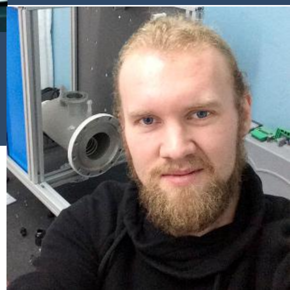
Egor Puzanov
Chemical Technology

Kseniya Otvagina
Chemistry

Amal Mechergui
Chemistry



Amin Kassaui
Chemical Technology



Nikolai Uglov
Chemical Technology

LMCP

LMCP

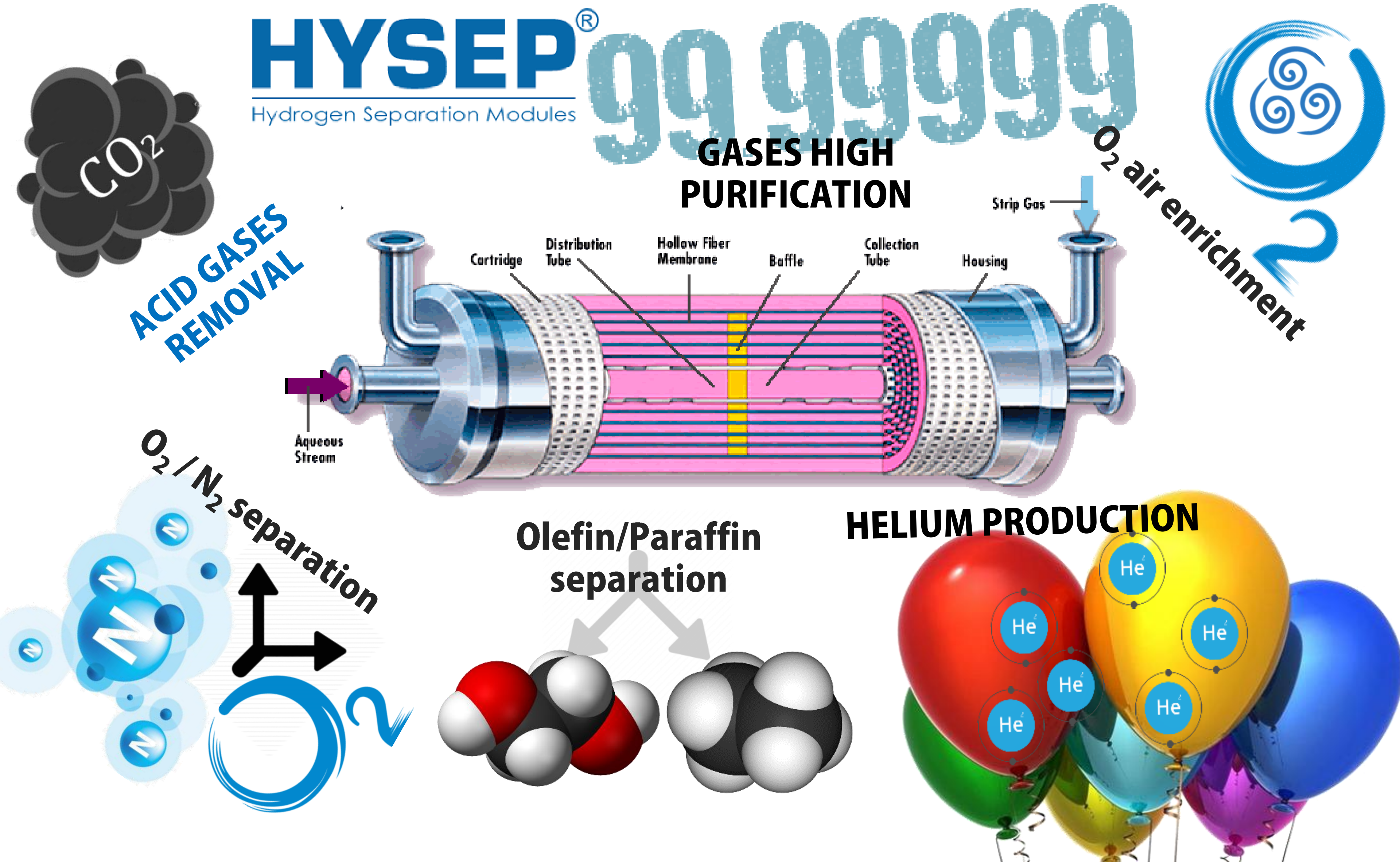
MATERIAL SCIENCE

- **NEW MEMBRANE MATERIALS**
  (Polymeric and ceramic)
- **HYBRID MEMBRANES**
  (MMM, SLIMS, POLYRTILS)

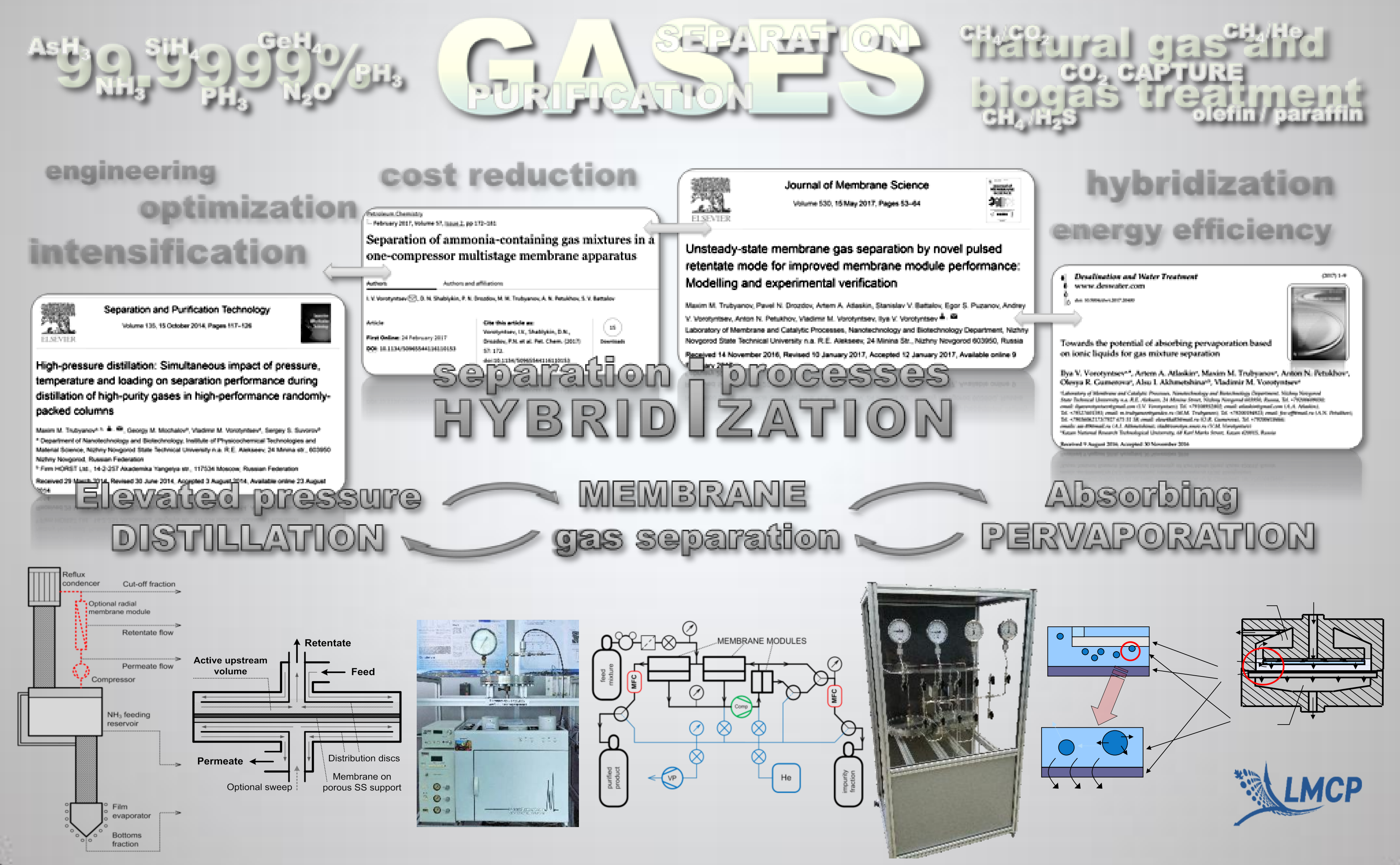
CHEMICAL ENGINEERING

- **INTENSIFICATION OF MEMBRANE PROCESSES**
  (Cascades, new module)
- **HYBRID PROCESSES**
  (Membrane contactors, Membrane Absortion)

APPLICATIONS OF MEMBRANE GAS SEPARATION



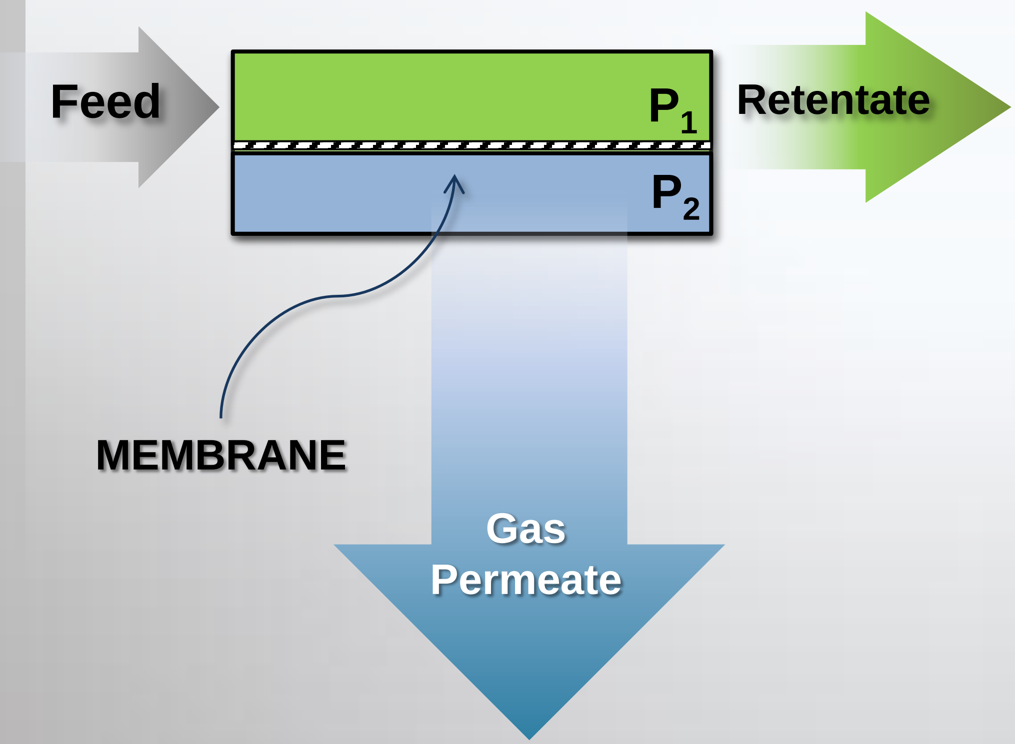
OUR SEPARATION AND PURIFICATION TECHNOLOGIES



SCHEME OF MEMBRANE GAS SEPARATION MODULE AND RECTIFICATION COLUMN

SINGLE-STAGE PROCESS
DIRECT CURRENT FLOW PROCESS

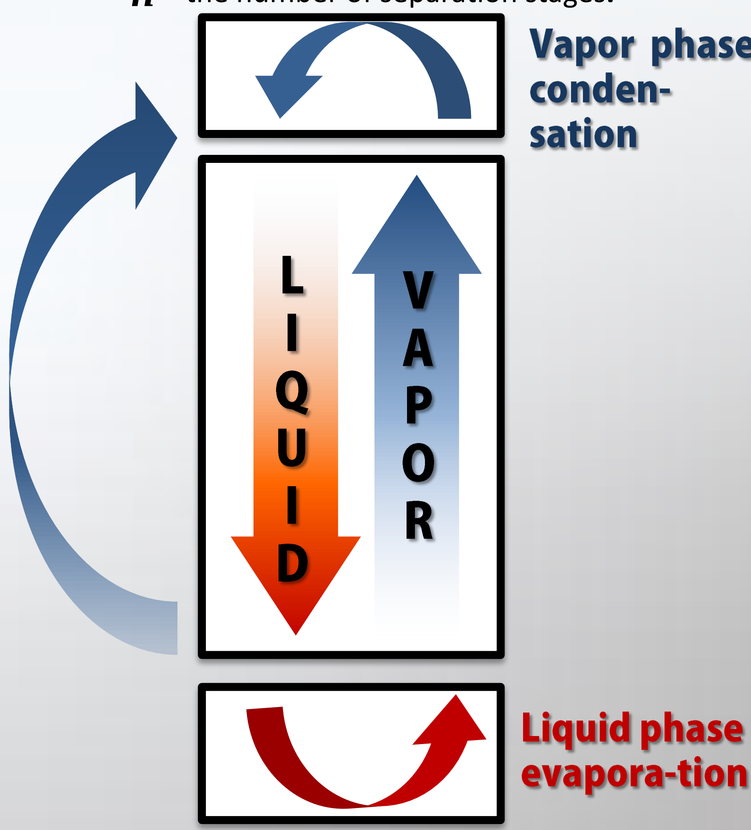
$T \sim 300K$ $\quad F \leq \alpha$



MULTI-STAGE PROCESS
COUNTER CURRENT FLOW PROCESS

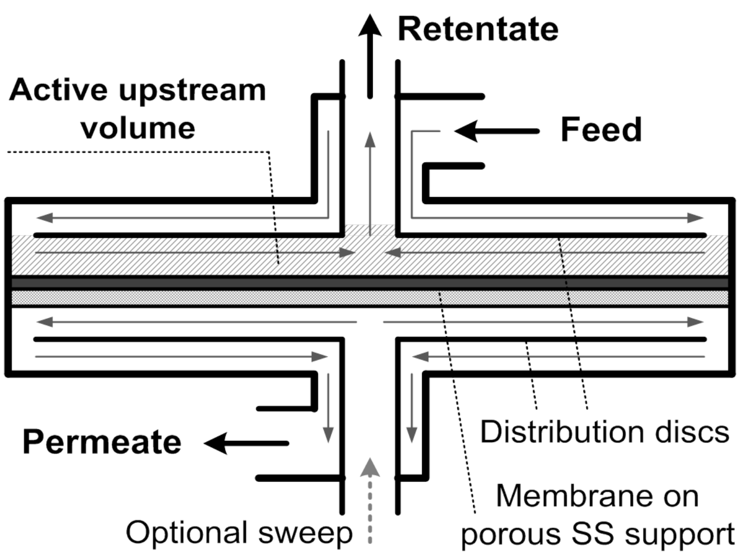
$F = \alpha_{l-v}^{n}$ $\quad T = T_{b.p.} << 300\,K$

n – the number of separation stages.

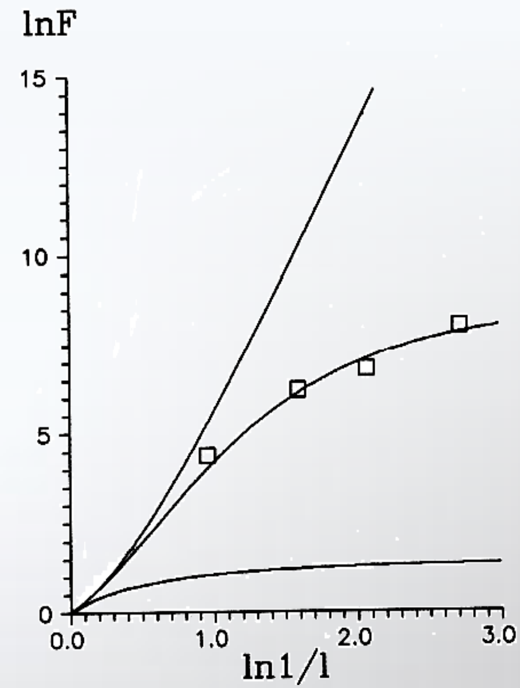


CHARACTERISTICS OF THE MEMBRANE MODULE

THE RADIAL COUNTERCURRENT MEMBRANE MODULE:



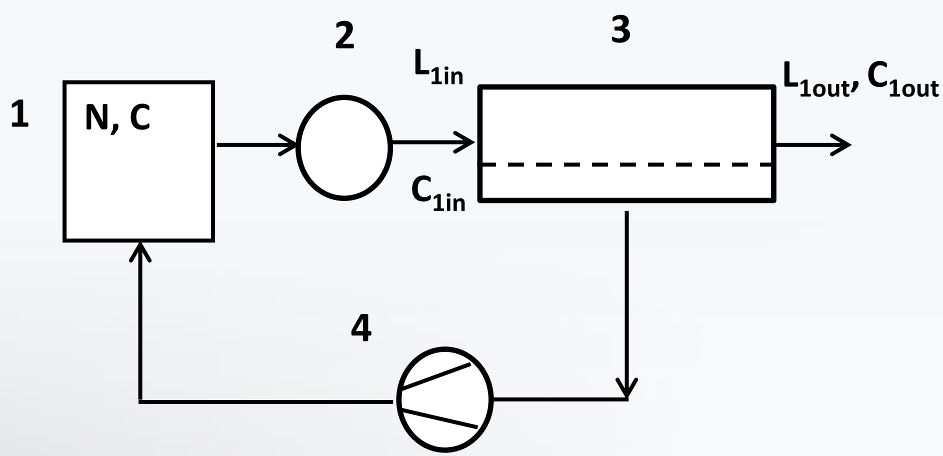
THE DEPENDENCE OF THE SEPARATION FACTOR *F* OF THE DEGREE OF SEPARATION MONOGERMANE (GeH_4) FROM WATER (H_2O)



1 – calculation according to the model of ideal displacement;
2 – calculation according to the model of complete mixing;
3 – experimental data

// Desalination. 2006. 200 (1-3) 232-233. DOI: 10.1016/j.desal.2006.03.307
// Desalination. 2002. 146 (1-3) 249-254. DOI: 10.1016/S0011-9164(02)00482-4

CASCADE OF MEMBRANE MODULE WITH FEEDING RESERVOIR (FD)



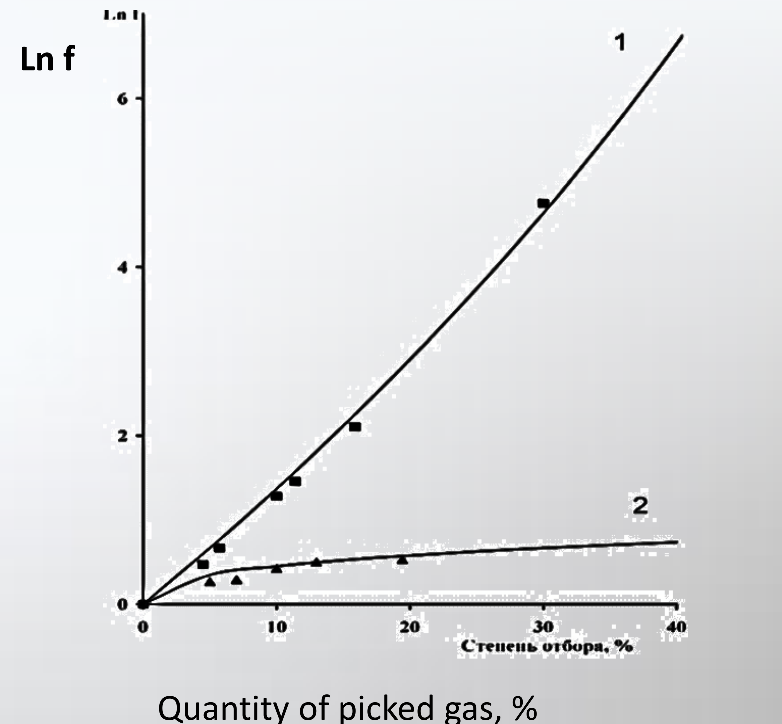
1 – feeding reservoir (FD); 2 – pressure reducer; 3 – membrane module; 4 – vacuum-compressor

$$f = \frac{C_0}{C} = \left(\frac{N_0}{N}\right)^{F^{-1}-1}$$

N_0 – quantity mole of the mixture in a FD at initial time,
N - quantity mole of the mixture in a FD after purification

Vorotyntsev V.M. et al . Petroleum Chemistry 2011 51 (8) 595-600.
Vorotyntsev V.M. et al . Inorg. Mat. 2009 45 (11) 1263–1266.

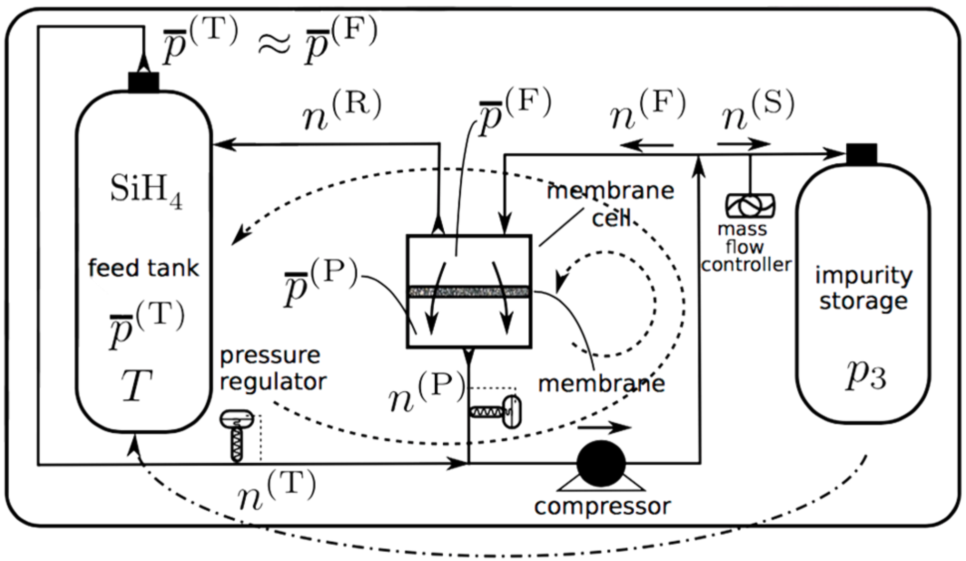
THE DEPENDENCE OF PURIFICATION RATIO FROM QUANTITY OF SAMPLED SUBSTANCES MIXTURE: R-12 (CF_2CL_2) – IMPURITY OF R-218 (C_3F_8)= 2.94



1 – membrane module with a feeding reservoir;
2 – single membrane module

PRACTICAL APPLICATION FOR ISOTOPE SILANE PURIFICATION

FAST-PERMEANT IMPURITY DEPLETION LOOP



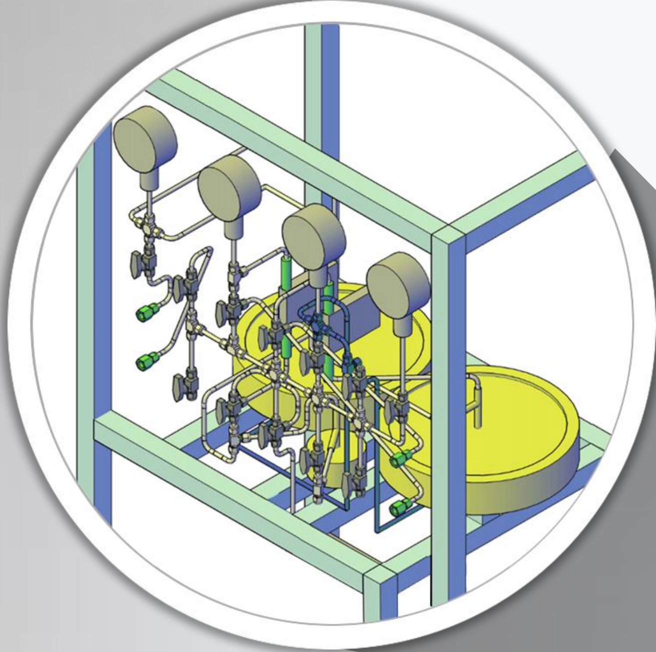
The silane product is concentrated in the feed tank via recirculation of the retentate, and the impurity is concentrated on the smaller loop which discharges to the impurity storage. The imply can be recycled as feed (dashed – dotted line).

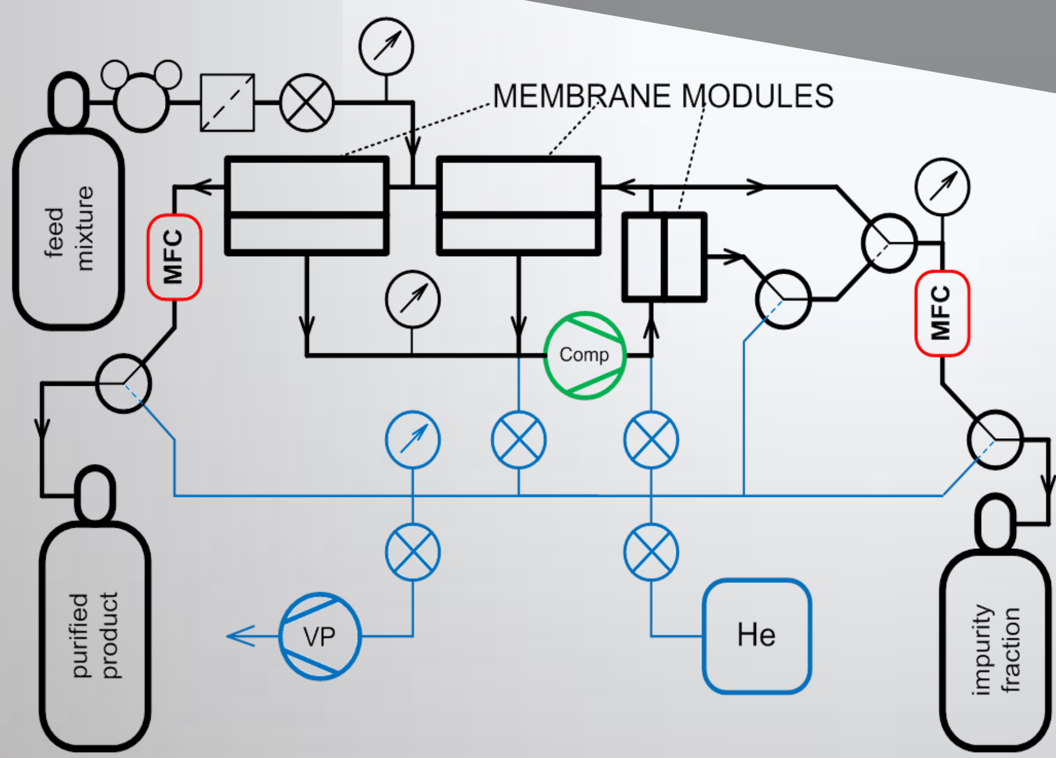
Valmor F. de Almeida, Kevin J. Hart, Journal of Membrane Science, V. 527, 2017, P. 164-179

EXPERIMENTAL SLOW-PERMEANT IMPURITY DEPLETION LOOP CURRENTLY IN TESTING

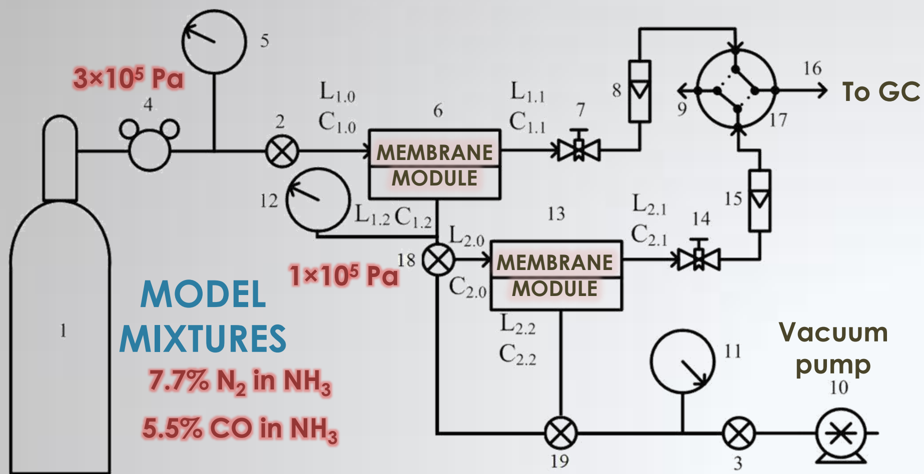
doi.org/10.1016/j.memsci.2016.12.049

MEMBRANE CASCADE TYPE OF «CONTINUOUS MEMBRANE COLUMN»





ONE-COMPRESSOR ONE-/TWO- STAGE MEMBRANE APPARATUS FOR AMMONIA-BASED MIXTURES SEPARATION



SEPARATION FACTOR:

$$F^{-1} = \frac{C_{1.1}}{C_{1.0}} = \left(\frac{L_{1.0}}{L_{1.1}}\right)^{(\alpha^*-1)/\alpha^*}$$ - ideal mixing regime

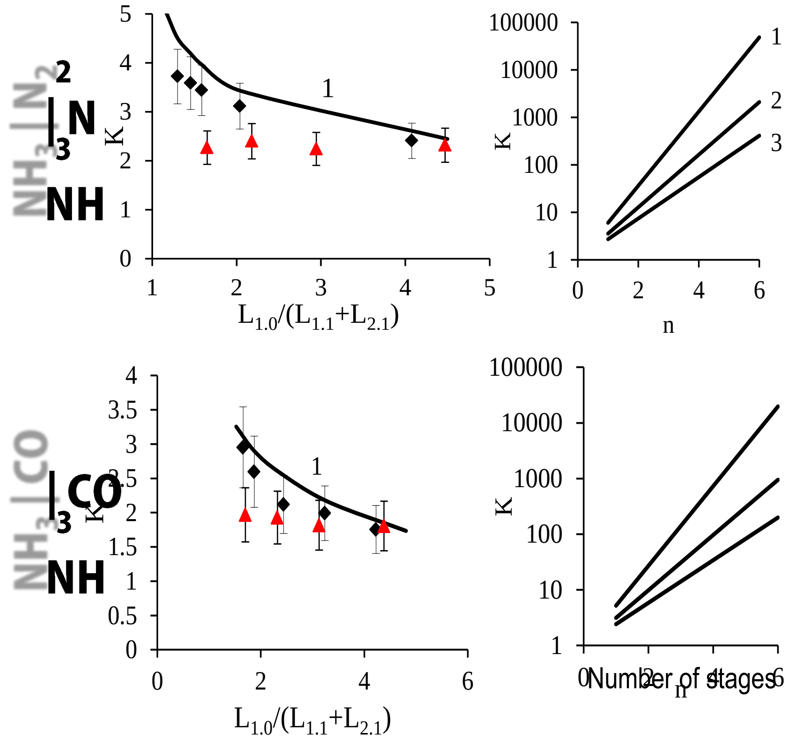
PURIFICATION DEGREE:

$$K = \frac{C_{1.0}}{C_{1.2}}$$

$$K_{1-n} = c_{1.0} / c_{n.2} = \left[\frac{\Theta}{1-(1-\Theta)F_i^{-1}}\right]^n = \left[\frac{\Theta}{1-(1-\Theta)^{\frac{1}{\alpha_i^*}}}\right]^n$$

ONE-COMPRESSOR MULTISTAGE MEMBRANE APPARATUS

PURIFICATION DEGREE



SAMPLING RATIO:

1 – 70%; 2 – 15%; 3 – 5%.

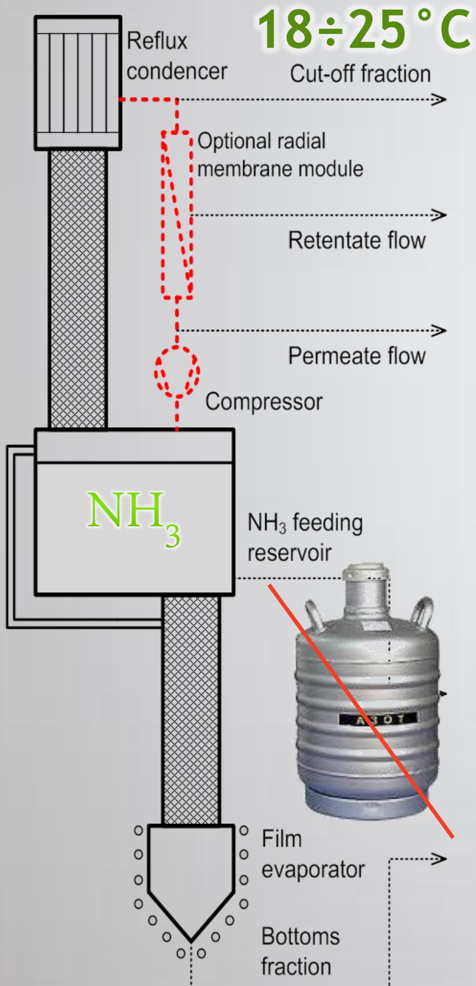
▲ — one stage of the cascade
◆ – two stages of the cascade

I.V. Vorotyntsev et al. Petroleum Chemistry (**2017**) 57 (2) 172-181

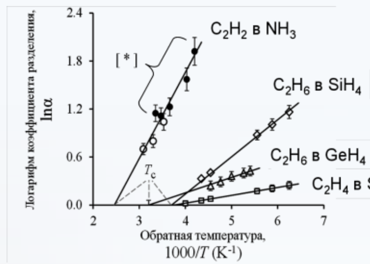
MEMBRANE SEPARATION + DISTILLATION UNDER ELEVATED PRESSURE

8÷12 atm

18÷25 °C

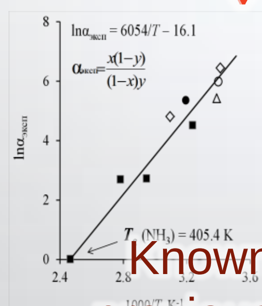


Decrease in liquid-vapor distribution coefficient



Примесь	α (239.8 K)	α (293 K)	*A*	$B \times 10^{-3}$
C_2H_2	**6.3±1.8**	**2.7±0.8**	–2.67	1.08
N_2 (H_2)	(2.8±0.2)×10[4]	920±80	–8.27	4.44
C_3H_6	100±10	12.2±0.9	–6.67	2.7
C_3H_8	490±60	29±5	–8.98	3.64
CH_3OH	[illegible]	27.2±2.2	–8.84	[illegible]
H_2O	(7.1[illegible])×10[4]	[illegible]00±80	–16.1	[illegible]

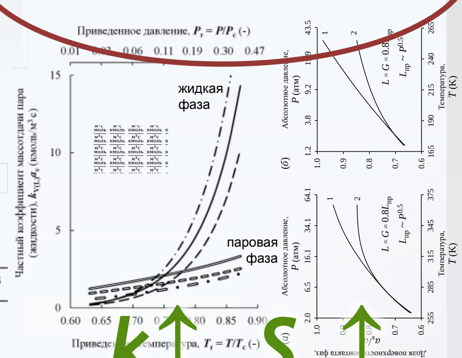
α↓ +



T, K	$x(H_2O)$	$\alpha_{эксп}$
294.3	0.095	400±80
295.1	0.010	230±50
313.2	0.115	210±40
323.1	0.040	120±25
339.5	0.044	15.3±3.1
359.6	0.029	14.9±2.9
405.7	0.007	**1.0±0.2**

Known previously

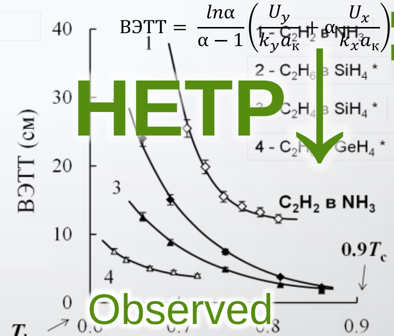
MASS-TRANSFER INTENSIFICATION



$k\uparrow$ $S_M\uparrow$

Высота, эквивалентная теоретической тарелке:

$$ВЭТТ = \frac{\ln\alpha}{\alpha - 1}\left(\frac{U_y}{k_y a_к} + \alpha\frac{U_x}{k_x a_к}\right)$$

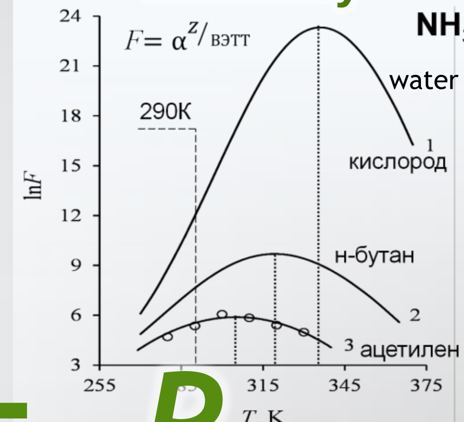


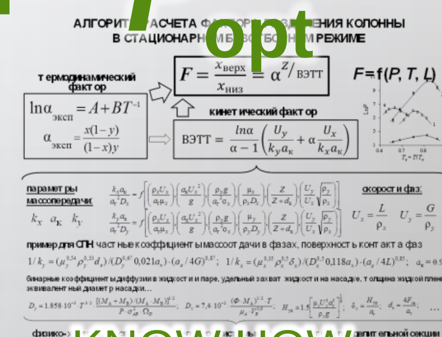
HETP↓

Observed and explained for the first time

= P_{opt}

OPTIMAL *P* & *T* for maximum efficiency



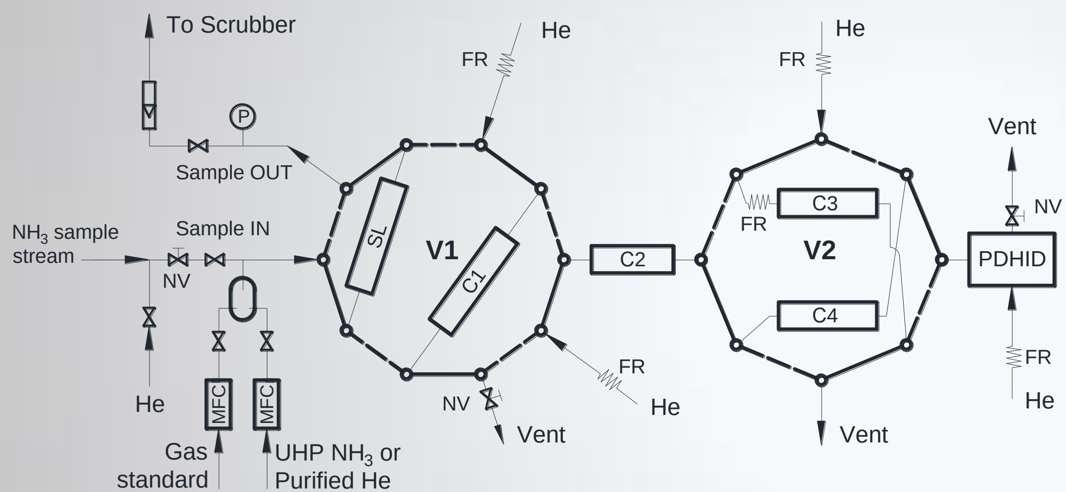


KNOW HOW

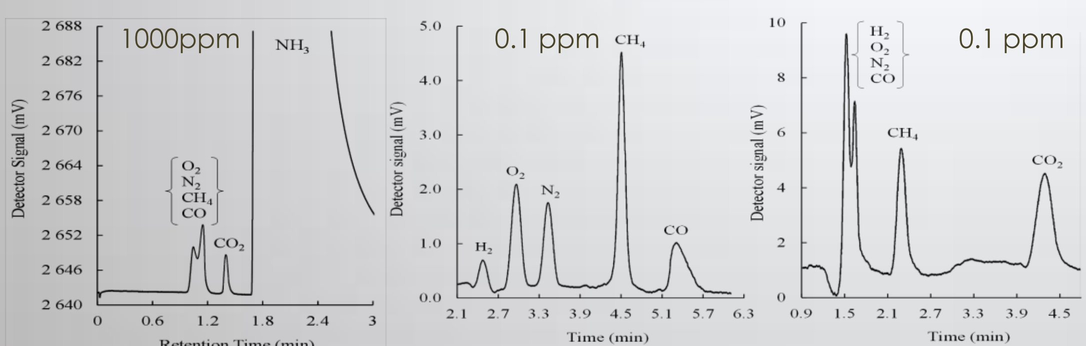
M.M. Trubyanov et al., Separation and Purification (2014) 135 117-126

MEMBRANE SEPARATION + DISTILLATION UNDER ELEVATED PRESSURE

Two-dimentional GC-PDHID|TCD analytical system for [sub-ppm ÷ 100%] determination of H_2, O_2, N_2, CH_4, CO, CO_2



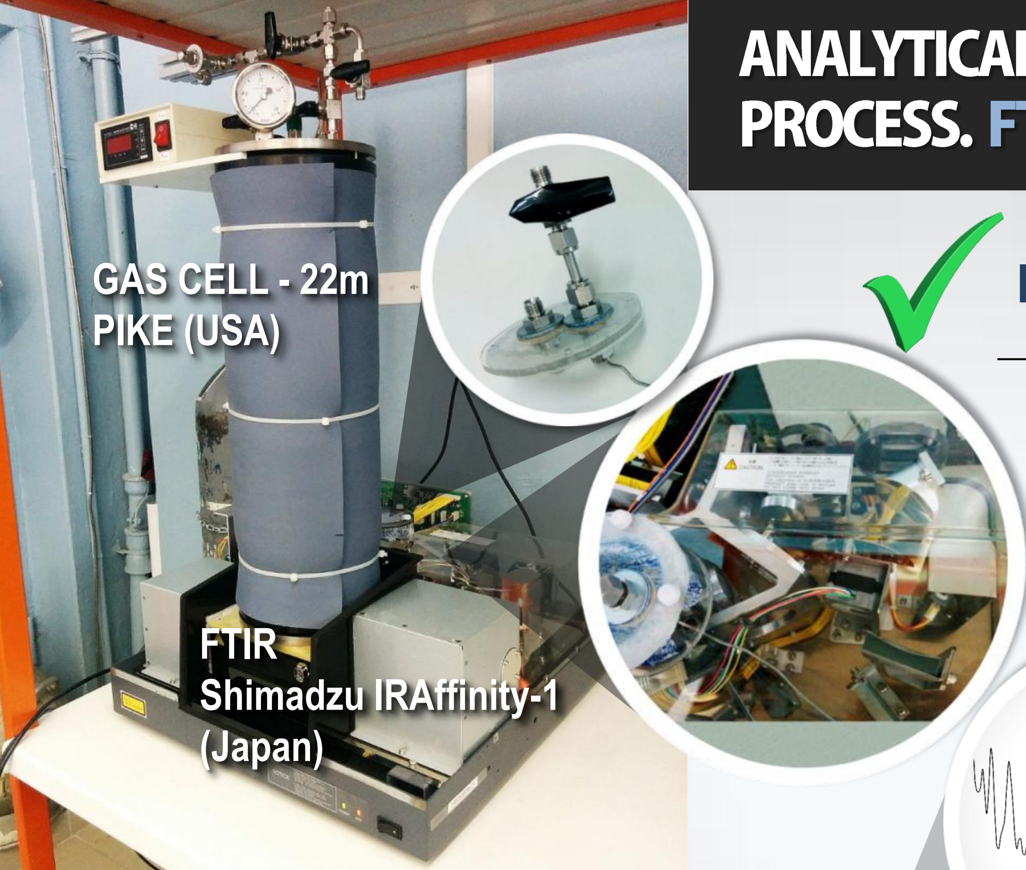
Chromatograms of impurities in ammonia



Component of the GC-system	Characteristics
Detector	PDHID D-2-I, 100°C
First column to separate the ammonia matrix, C1	15% PEG-600 on PTFE, 70°C 60/80 mesh 3 m × 3 mm i.d.
Analytical column, C3 (for H_2, O_2, N_2, CH_4, CO)	13X molecular sieve, 70°C 60/80 mesh 1 m × 2 mm i.d.
Analytical column, C4 (for CO_2)	Porapak Q, 70°C 60/80 mesh 4 m × 2 mm i.d.
Trace ammonia trap, C2	$NaHSO_4$, 70°C 40/60 mesh 0.3 m × 3 mm i.d.
Sample loop, SL	1.5 ml, 70°C
Carrier gas, He	He 99.99999+%, 30 ml/min

M.M. Trubyanov et al. Journal of chromatography A (2016) 1447 129-134

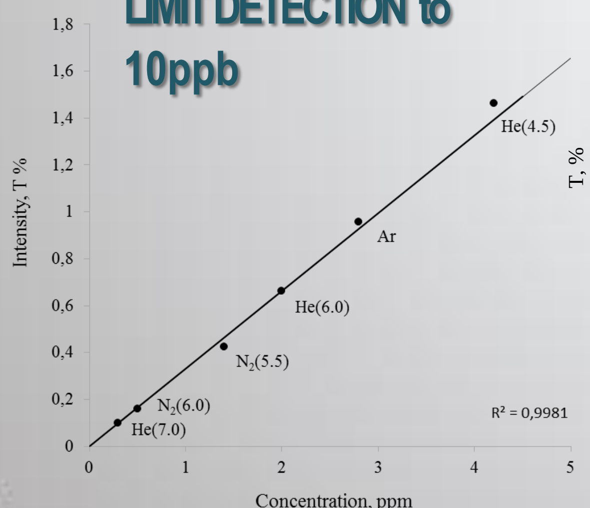
ANALYTICAL CONTROL OF THE PURIFICATION PROCESS. FTIR

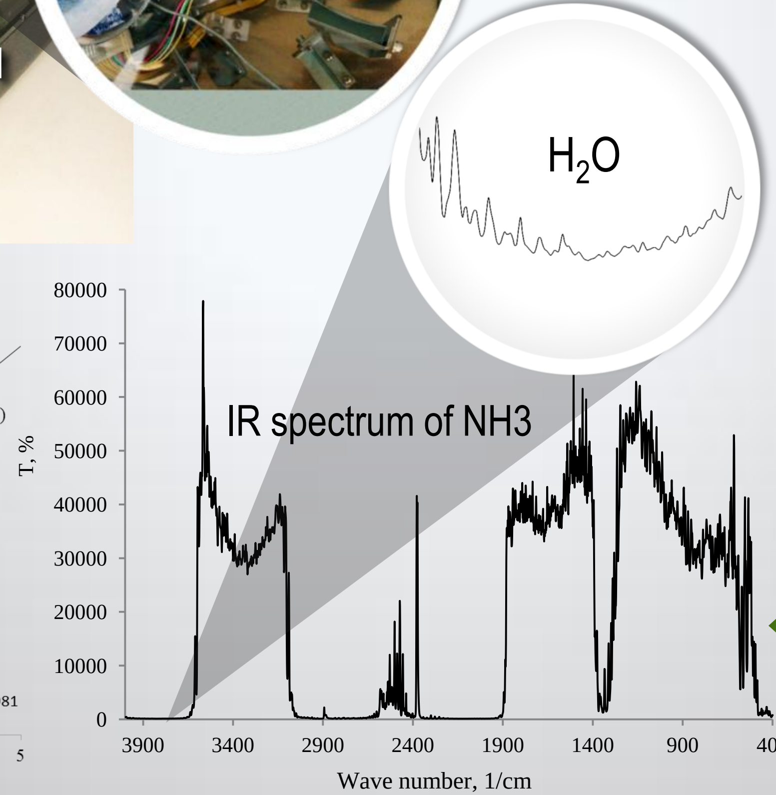


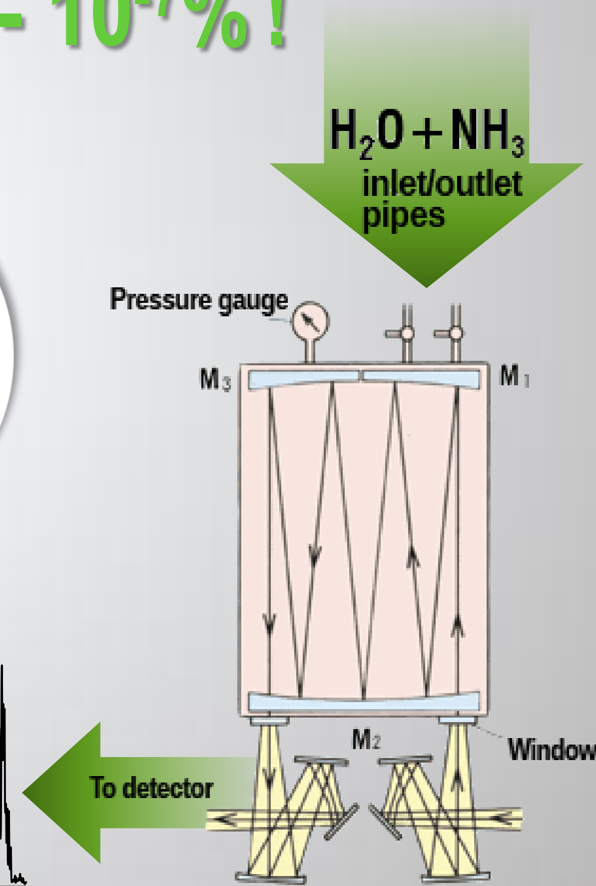
RECORDLY LOW LIMITS OF DETECTION

100% - 10^{-7}% !

LIMIT DETECTION to 10ppb

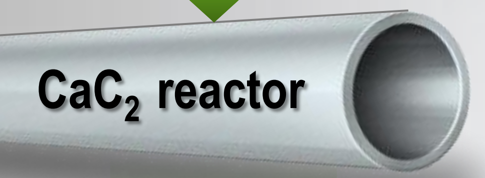






ANALYTICAL CONTROL OF THE PURIFICATION PROCESS. GAS CHROMATOGRAPHY

$NH_3 + H_2O$

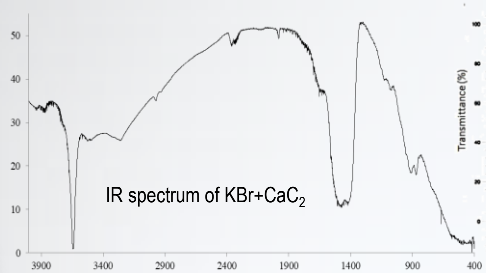


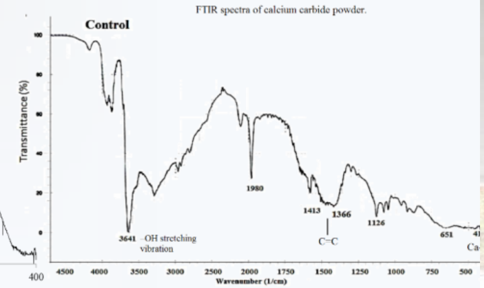
CaC_2 reactor

$NH_3+C_2H_2$

ХРОМОС ГХ-1000 (RUSSIA) + PDHID (Valco VICI, USA)

C_2H_2

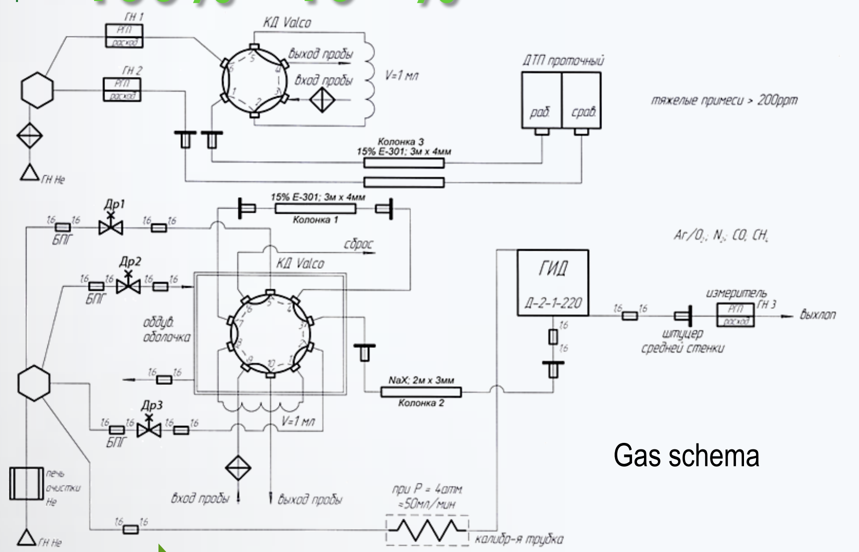




Mr. Trivedi. Effect of Biofield Energy Treatment on Physical and Structural Properties of Calcium Carbide and Praseodymium Oxide

LIMIT DETECTION

$100\% - 10^{-4}\,\%$



Gas schema

Planetary ball mill PM100 Retsch (USA)

CONCENTRATIONS

$C_2H_2 \backsim H_2O$

$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$

$CaC_2 + Ca(OH)_2 \rightarrow C_2H_2 + 2CaO$

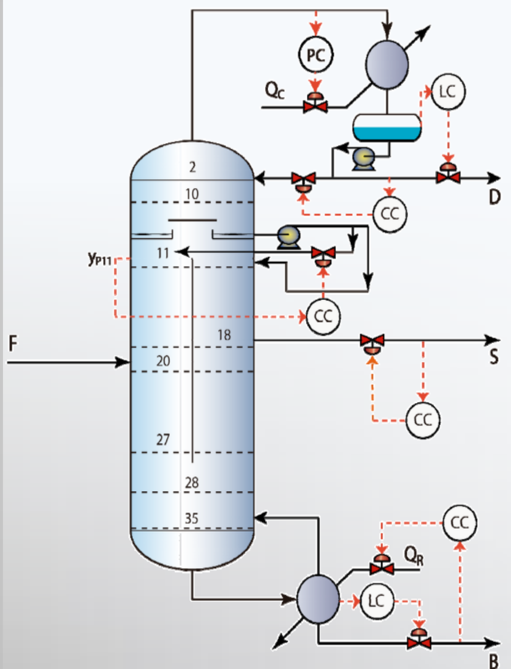
$CaC_2 + H_2O \rightarrow$ **HO-Ca-C≡CH**

$HO\text{-}Ca\text{-}C{\equiv}CH + H_2O \rightarrow C_2H_2 + Ca(OH)_2$

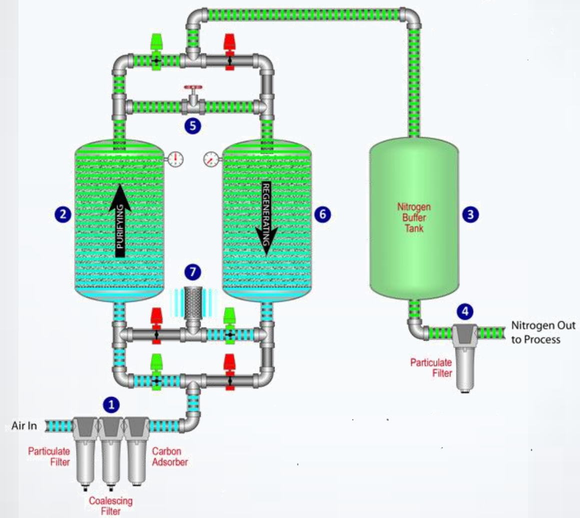
$HO\text{-}Ca\text{-}C{\equiv}CH \rightarrow CaO + C_2H_2$

EXAMPLES OF UNSTEADY-STATE PERIODICAL SEPARATION TECHNIQUES

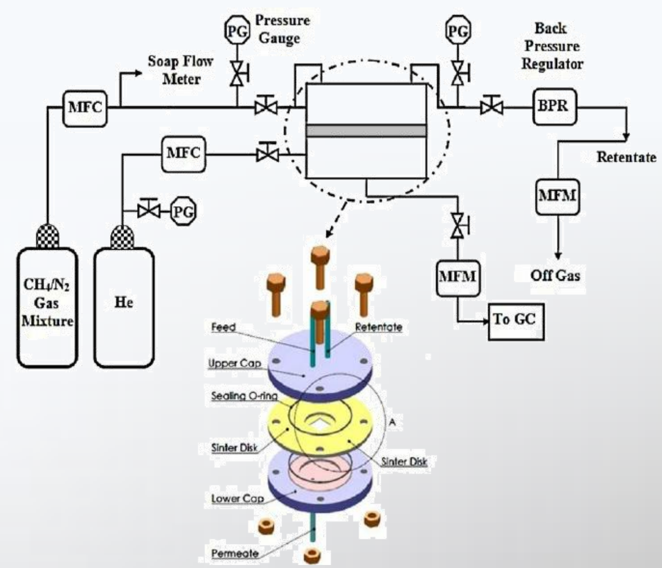
DISTILLATION

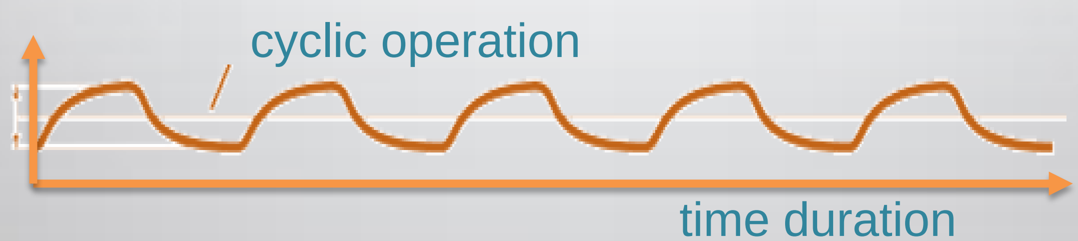


PRESSURE SWING ABSORPTION



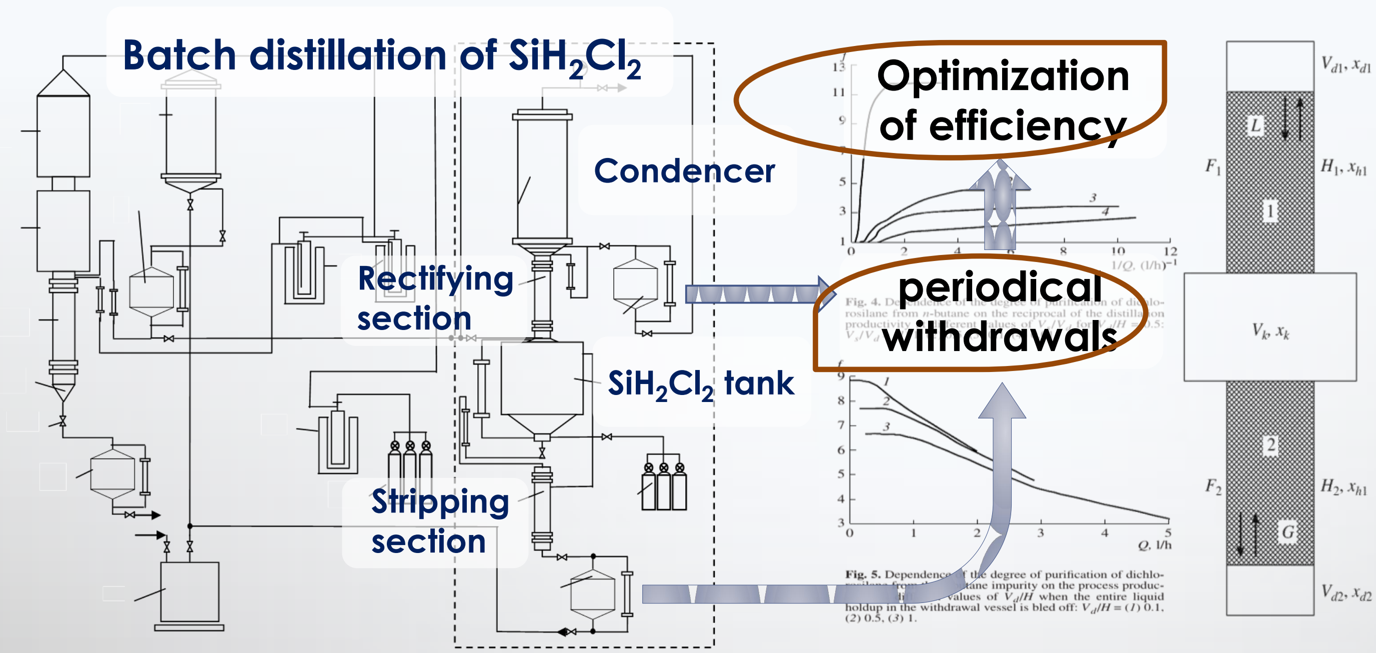
MEMBRANE SEPARATION





BATCH DISTILLATION WITH PERIODICAL WITHDRAWALS

Kinetics of concentrating and ultrapurifying dichlorosilane by batch distillation with periodical withdrawals



Current and disturbed Separation Factors

$$F_{1,2} = \frac{x_{d1,2}(1-x_k)}{(1-x_{d1,2})x_k} \qquad \tilde{F}_{1(2)} = F_{1(2)}^{\frac{H_{1(2)}-V_{s1(2)}}{H_{1(2)}}}$$

Relaxation time for the disturbed separation factor

$$t = \alpha \frac{\left[V_d(F_0-1) + \left(\frac{F_0-1}{\ln F_0} - 1\right)H\right]}{L(\alpha-1)} \ln\frac{F_0-1}{F_0-F}$$

V.M. Vorotyntsev et al., Theoretical Foundations of Chemical Engineering, 2007

UNSTEADY-STATE MEMBRANE GAS SEPARATION BY CONCENTRATION PULSE

PULSED INPUT OF THE FEED MIXTURE

Separated mixture

He : CO_2 = 1 : 1

Membrane

PVTMS

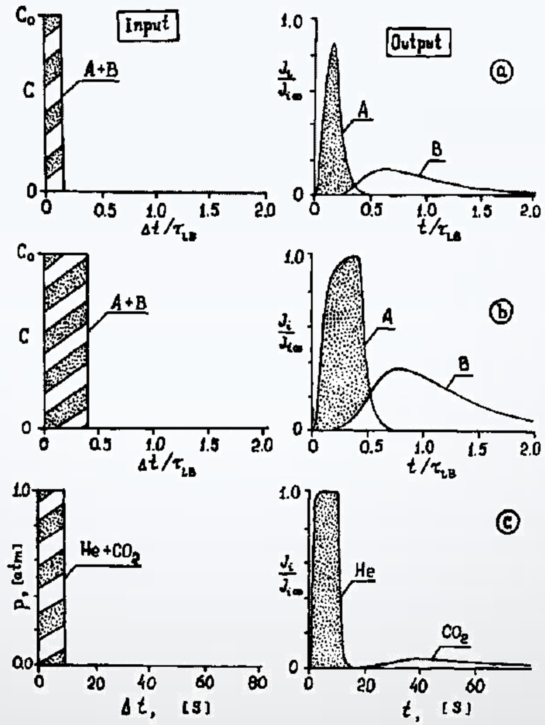
Equal permeability

$P_{He} \approx P_{CO2}$ ✗

Different diffusivity

$D_{He} \approx 47\ D_{CO2}$ ✓

PULSED INPUT

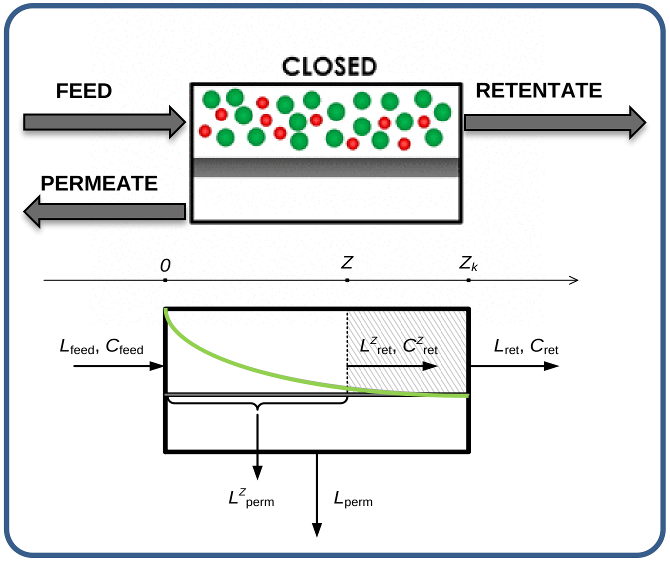


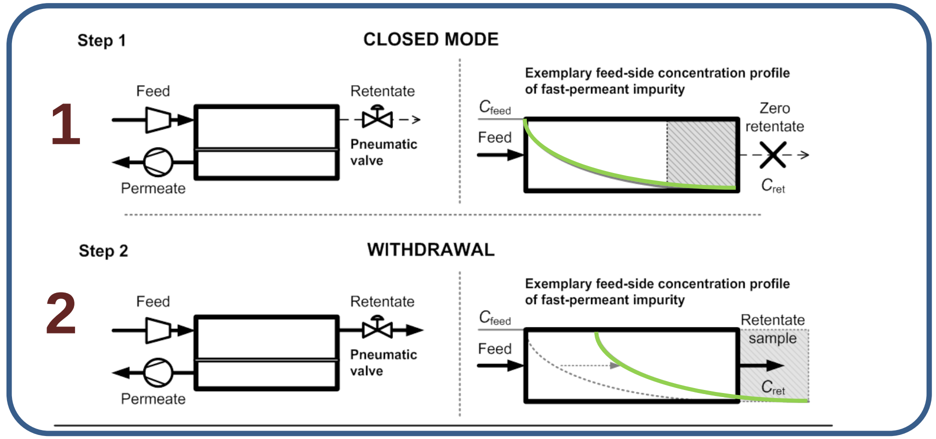
- Separation on non-selective membrane
- Increase in selectivity for **diffusion-controlled** separation
- **Decrease in productivity**

I.N. Beckman, A.B. Shelekhin, J. of Membrane Sci, 1991

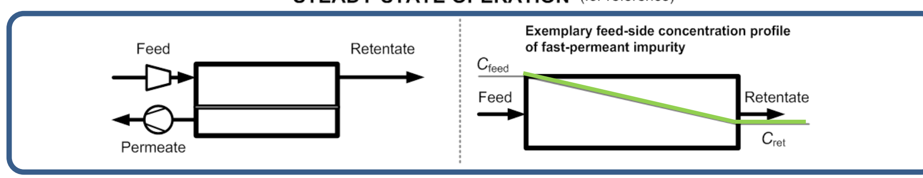
UNSTEADY-STATE MEMBRANE GAS PURIFICATION BY PERIODICAL WITHDRAWALS

Working principle of Pulsed retentate operation



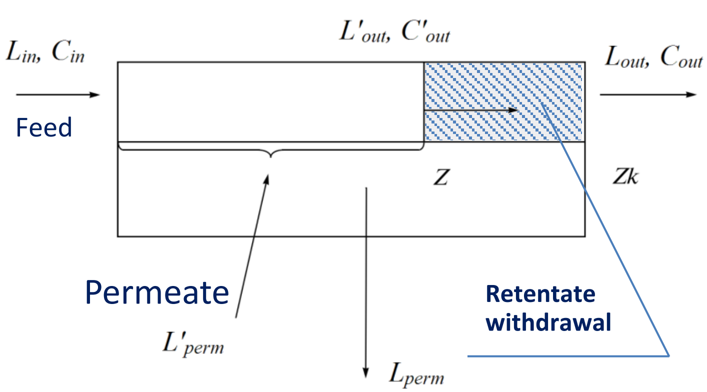


STEADY-STATE OPERATION (for reference)



Removal of highly penetrating impurity

Theoretical modeling



Separation factor (pulsed mode)

$$F' = \frac{C_{in}}{C'_{out}} = \left(\frac{L_{in}}{L'_{out}}\right)^{\alpha^*-1}$$

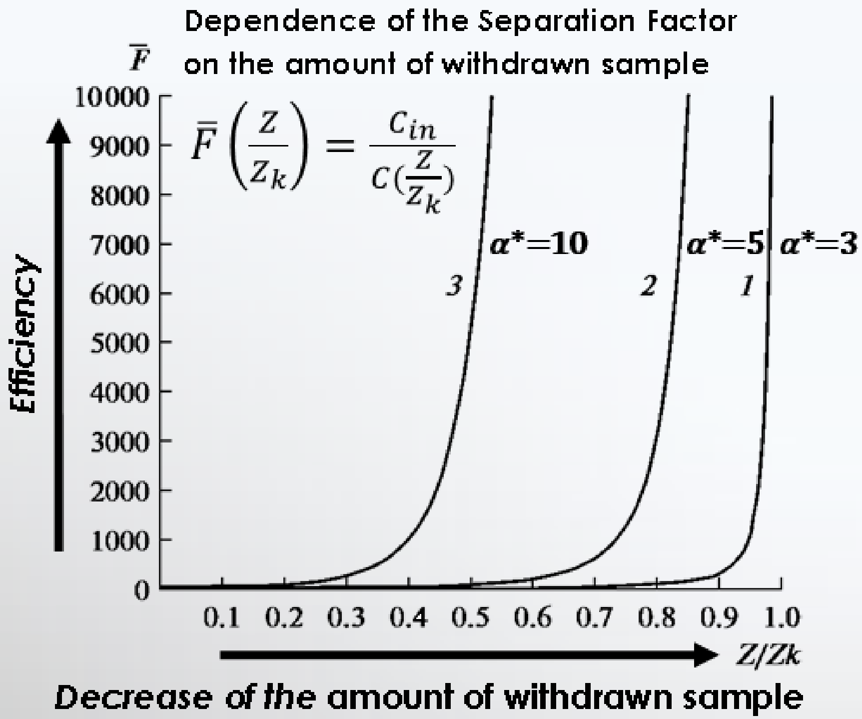
$$\alpha^* = \alpha \Big/ 1 + (\alpha - 1)\frac{P_2}{P_1}$$

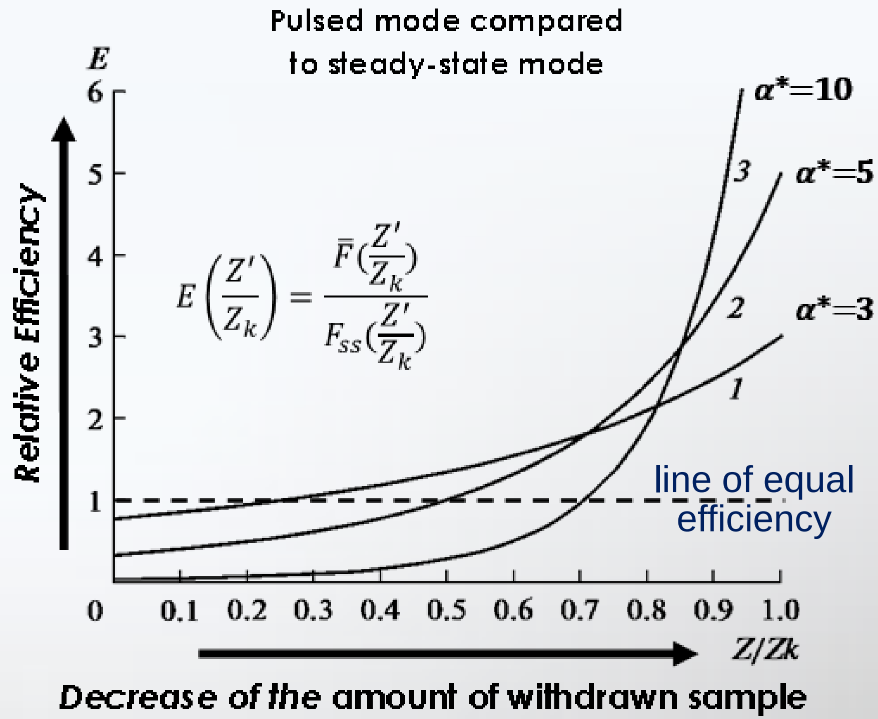
C_{in}/C'_{out} - inlet and outlet concentrations ratio; L_{in}, L_{out}, L_{perm} – inlet, outlet, permeate fluxes; α – ideal selectivity; α^* - effective selectivity; P_2 and P_1 – permeate and feed pressure

M.M. Trubyanov et al., Journal of Membrane Science (2017) 530 53–64

SEPARATION EFFICIENCY SIMULATIONS RESULTS

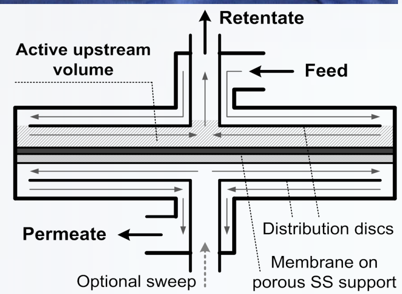
Efficiency vs productivity compared to steady-state





M.M. Trubyanov et al., Journal of Membrane Science (2017) 530 53–64

EXPERIMENTAL SETUP FOR UNSTEADY-STATE MEMBRANE GAS SEPARATION



SYSTEM DESCRIPTION

Membrane

Poly(arylate-siloxane) Silar®

Gas mixture

$N_2 : N_2O = 1 : 0.01$

$\alpha_{ideal}(N_2O / N_2) = 12.0 \pm 0.7$

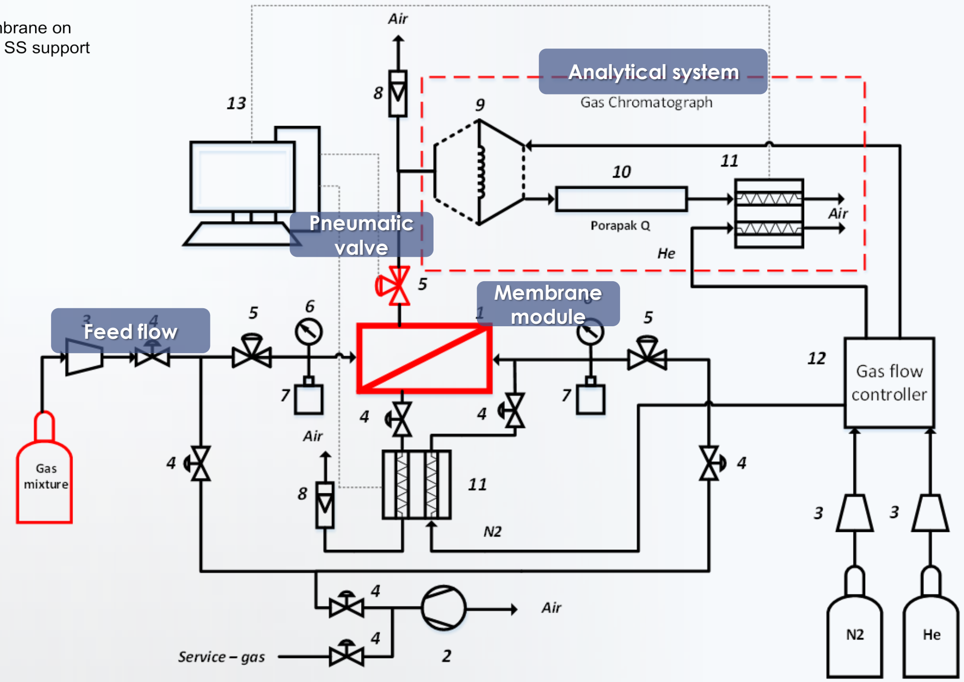
Operational parameters

- Stage cut
- Pressure ratio
- $\Delta\tau_{open}$ – duration of withdrawal
- $\Delta\tau_{close}$ – duration of stripping
- $\Delta\tau_{total}$ – total cycle duration
- Sample amount ratio

Nitrogen-based model mixtures and GC conditions

Gas	Q (Barer)	α_{id}	α_{ef}
N_2	200±5	-	-
CH_4	550±15	2.75±0.15	2.7±0.5
CO_2	1800±50	9.0±0.5	7.5±1.5
N_2O	2400±70	12.0±0.7	10±2

Component of the GC	Characteristics
Detector	TCD, 100mA, 100°C
Chromatographic column	Porapak Q, 60/80 mesh, 80°C 2 m × 3 mm i.d. stainless steel tube
Sample loop	3 ml, 80°C
Carrier gas	He 99.9999%, 30 ml/min

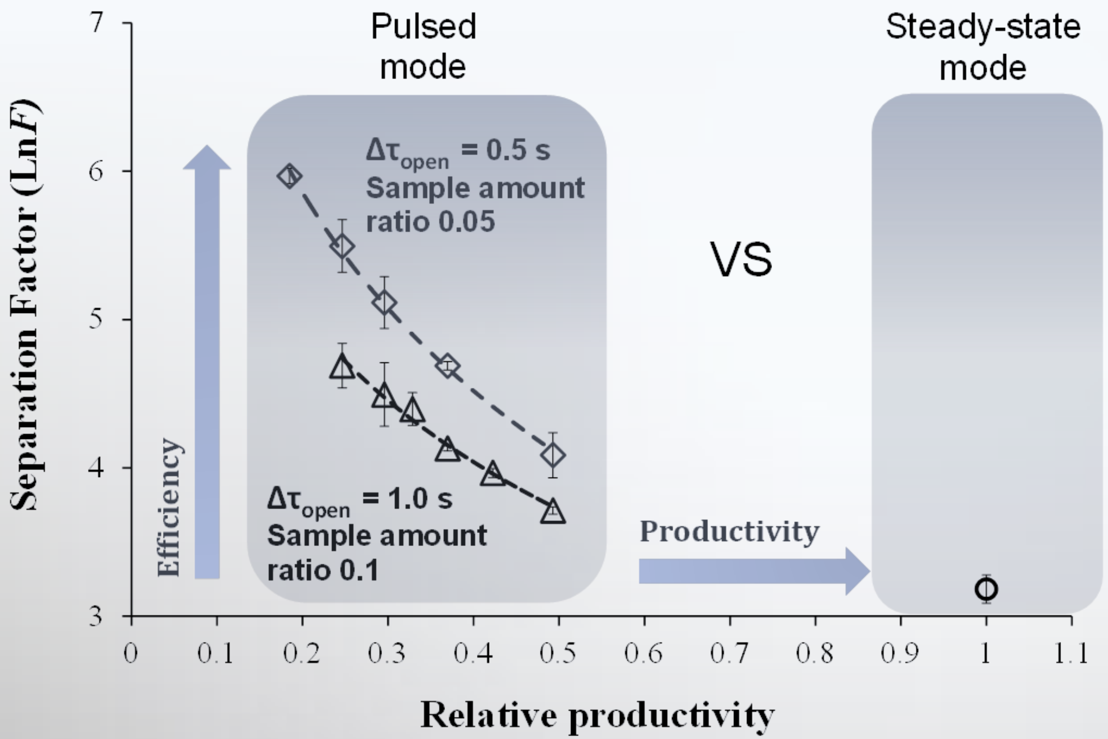


High-efficient radial membrane module in counter-current mode:

low variation of the gas linear velocity
helps to provide the laminar gas flow
eliminates any trapped gas or dead zones

M.M. Trubyanov et al., Journal of Membrane Science (2017) 530 53–64

COMPARISON OF A PULSED MODE AND A STEADY-STATE MODE



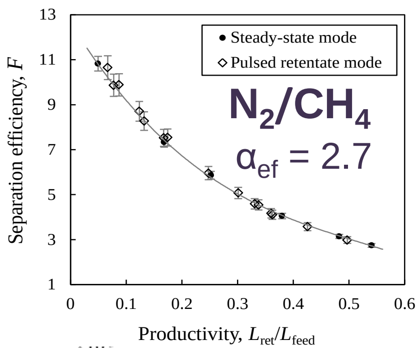
- Significant increase in separation efficiency at decreasing productivity
- Separation efficiency is higher for smaller samples at same productivity

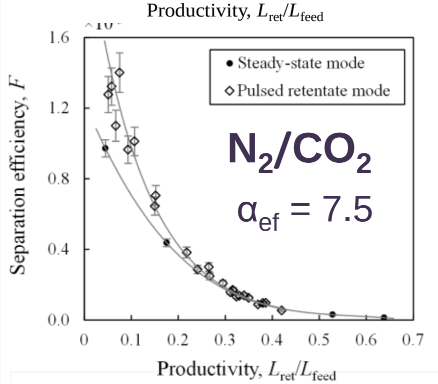
M.M. Trubyanov et al., Journal of Membrane Science (2017) 530 53–64

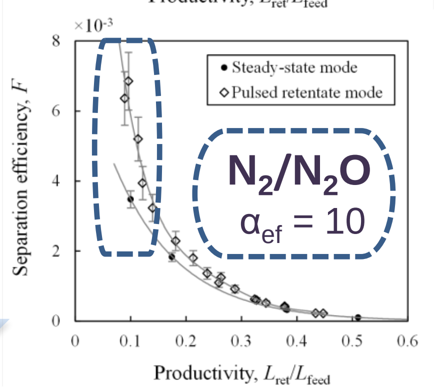
DETAILED EXPERIMENTAL VERIFICATION

SEPARATION OF BINARY MIXTURES IN RADIAL COUNTERCURRENT MEMBRANE MODULE IN TWO REGIMES

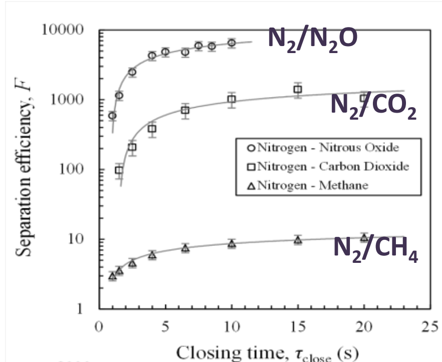
The higher the selectivity the higher the efficiency improvement



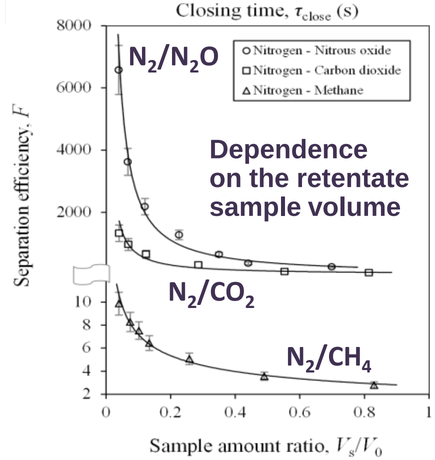




APPROACHING CLOSED MODE OPERATION



Time period to reach a steady-state condition of a closed mode; opening time is 0.5 s for each data point.

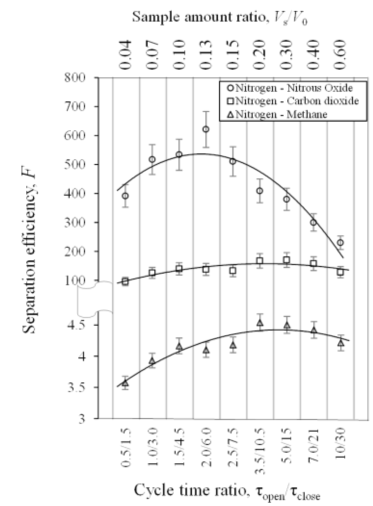


Separation performance depending on retentate sample amount ratio (*Vs* volume of retentate sample, and V_0 active upstream volume).

Remarks

- Separation efficiency increases with the increase of stripping time
- With the increase of stripping time the system approaches closed mode operation
- Smallest retentate sample volume provides the highest separation efficiency

OPTIMIZATION PERSPECTIVES

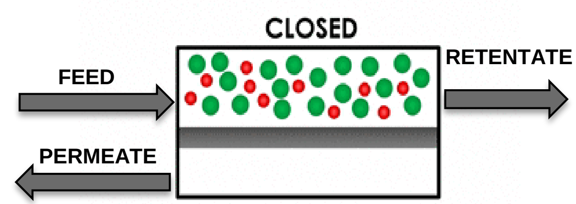


Separation performance of a pulsed retentate operation for different cycle times at constant productivity (opening to closing time ratio is 1/3).

- **SAME productivity $\Delta\tau_{open}/\Delta\tau_{total}$ = 1 / 3**
- **increasing amounts of withdrawn samples**

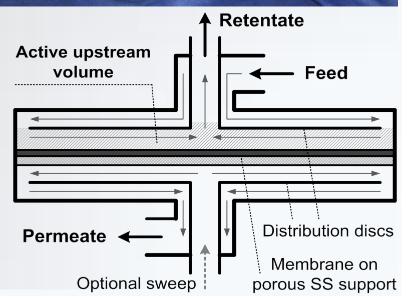
NON-MONOTONIC DEPENDENCE

mutual influence of the amount of withdrawn sample and the stripping time

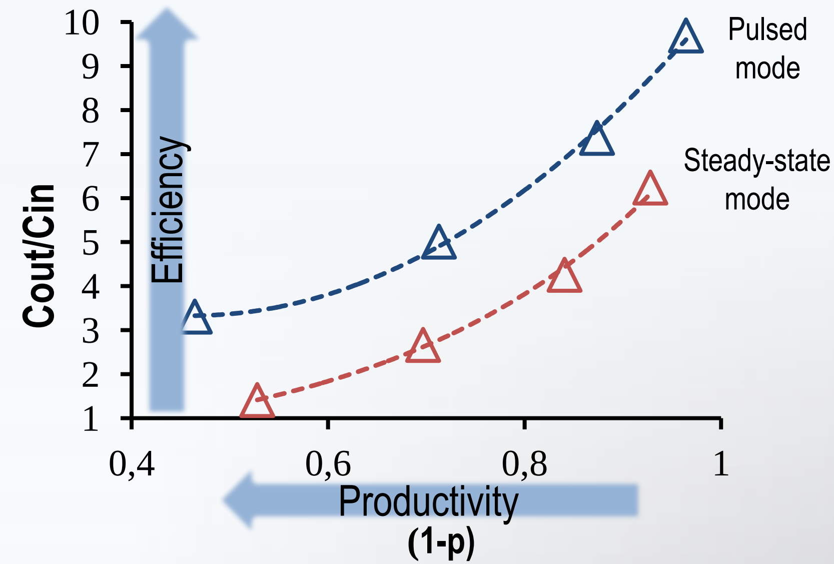


M.M. Trubyanov et al., Journal of Membrane Science (2017) 530 53–64

UNSTEADY-STATE MEMBRANE GAS SEPARATION WITH PERMEATE RECYCLE FOR LOW PERMEABLE COMPONENT CONCENTRATION SETUP

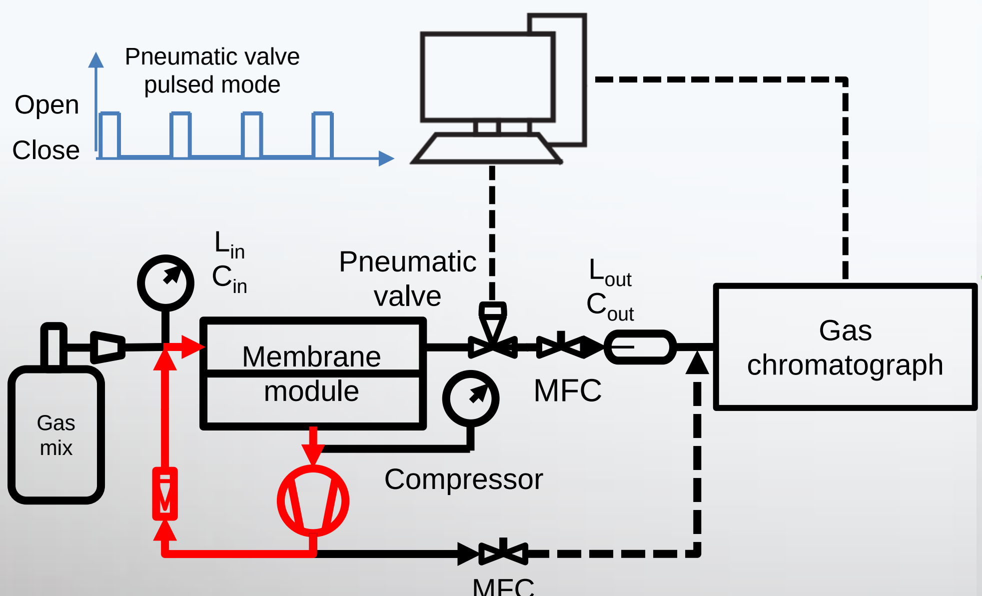


COMPARISON OF A PULSED MODE AND A STEADY-STATE MODE



Membrane – SILAR
Pressure ratio – 1.1 bar
Gas mixture – N_2O/N_2 = 99/1%

Principal scheme of unsteady-state membrane gas separation with permeate recycle for Low permeable component concentration setup



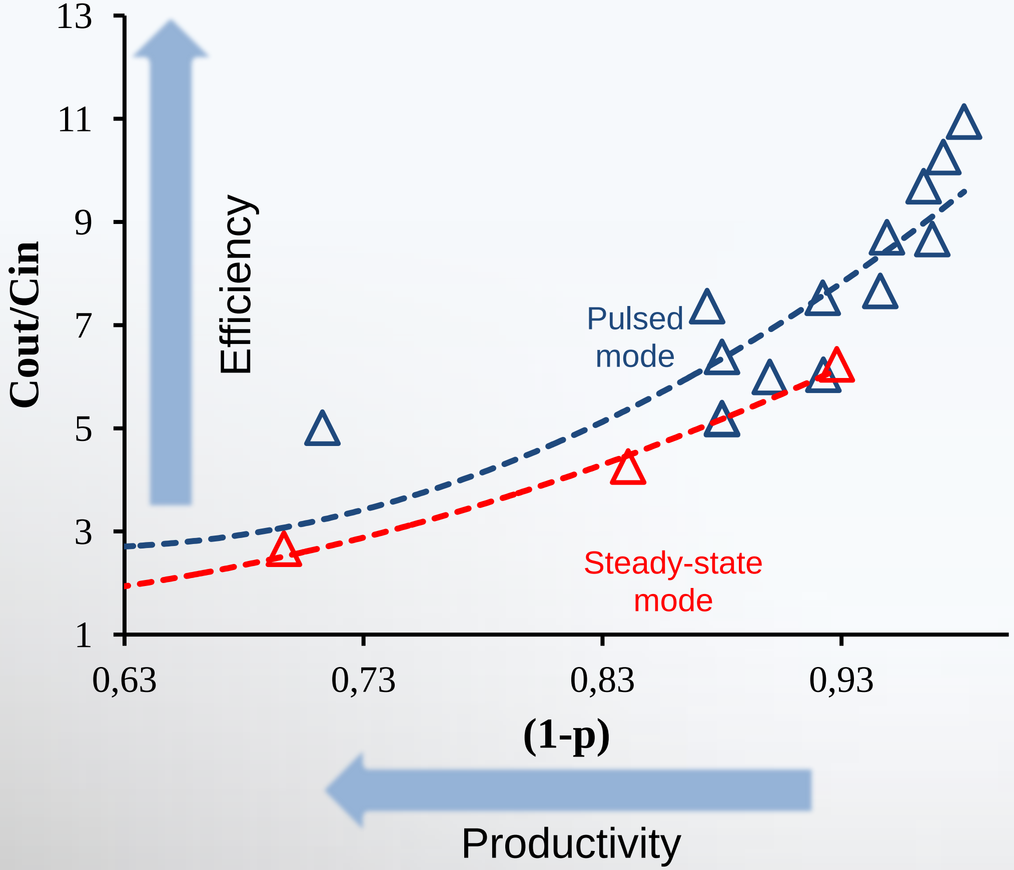
- Separation efficiency is higher for whole range of withdrawal rate
- Significant increase in separation efficiency at decreasing productivity

$$p = L_{out}/L_{in}$$

(1-p) = 1 **Minimum productivity**

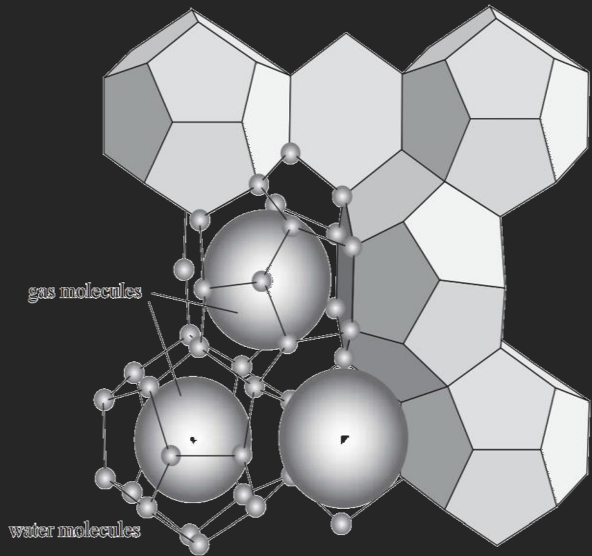
(1-p) = 0 **Maximum productivity**

PRELIMINARY EXPERIMENTAL RESULTS

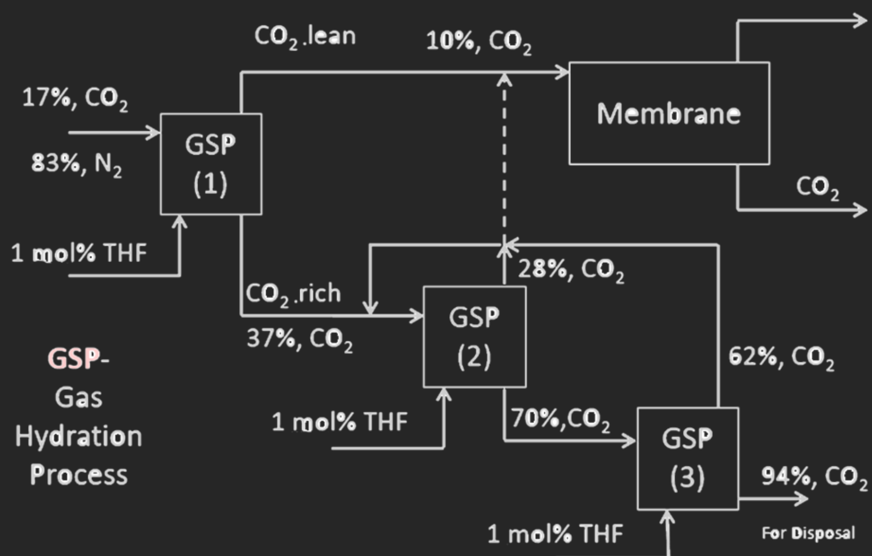


- Pulsed operation in permeate recycle mode with low permeable component concentration is more efficient in whole investigated range
- Optimization is required to determine most effective conditions of pulsed operation

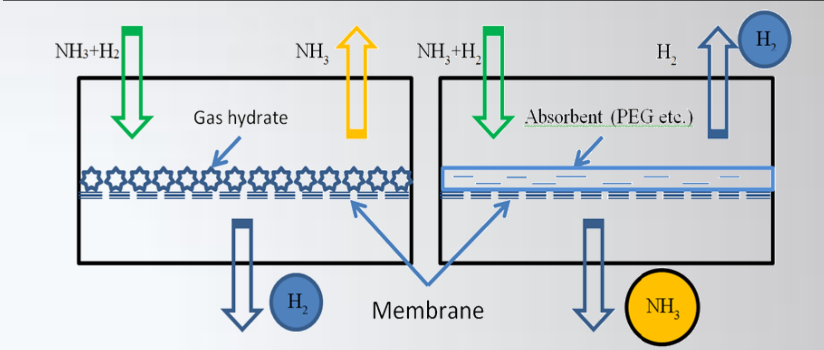
CASCADE OF MEMBRANE MODULE + GAS HYDRATE CRYSTALLIZATION

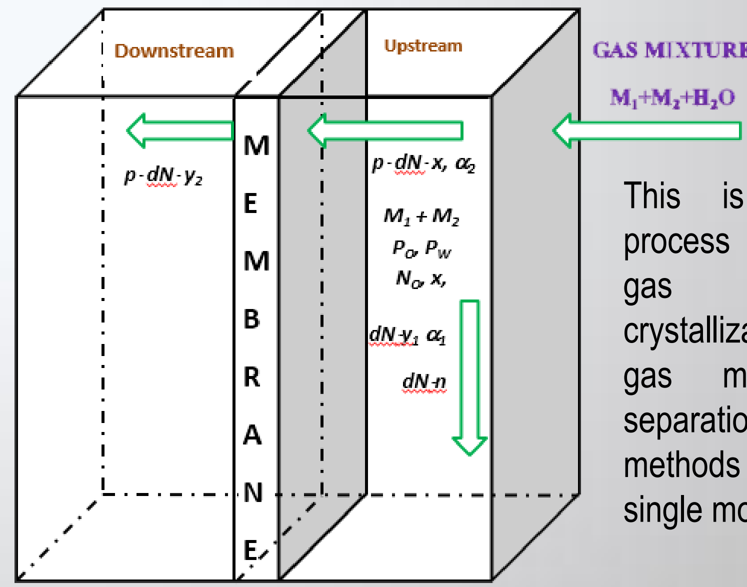


A hybrid hydrate-membrane process for CO_2 recovery from flue gas in the presence of THF as additive. Hydrate formation is carried out at 273.75 K and 2.5 MPa in the three stages.



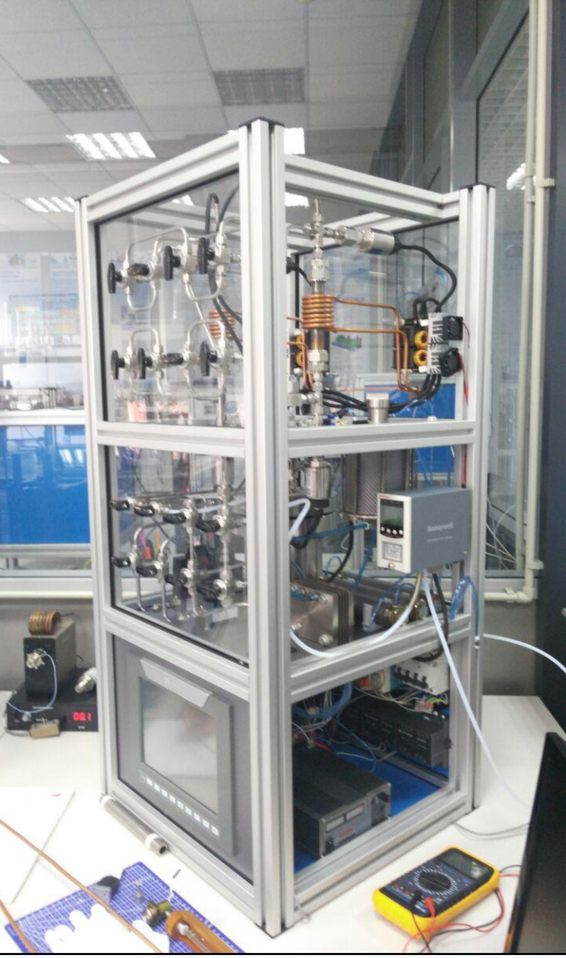
SCHEME OF THE HYBRID GAS HYDRATE-MEMBRANE SEPARATION METHOD



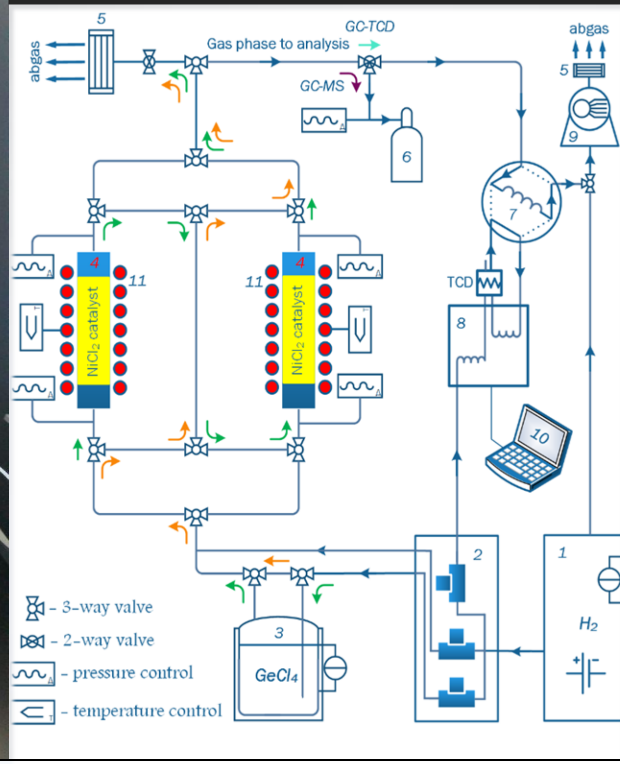


This is hybrid process including gas hydrate crystallization and gas membrane separation methods in the single module.

P. Linga, A. Adeyemo, and P. Englezos // Environ. Sci. Technol., 42(2008), 315–320



ENERGY SAVING CATALYTIC PROCESSES



CATALYSTPREPARATION PROCEDURE

CATALYST PREPARATION PROCEDURE

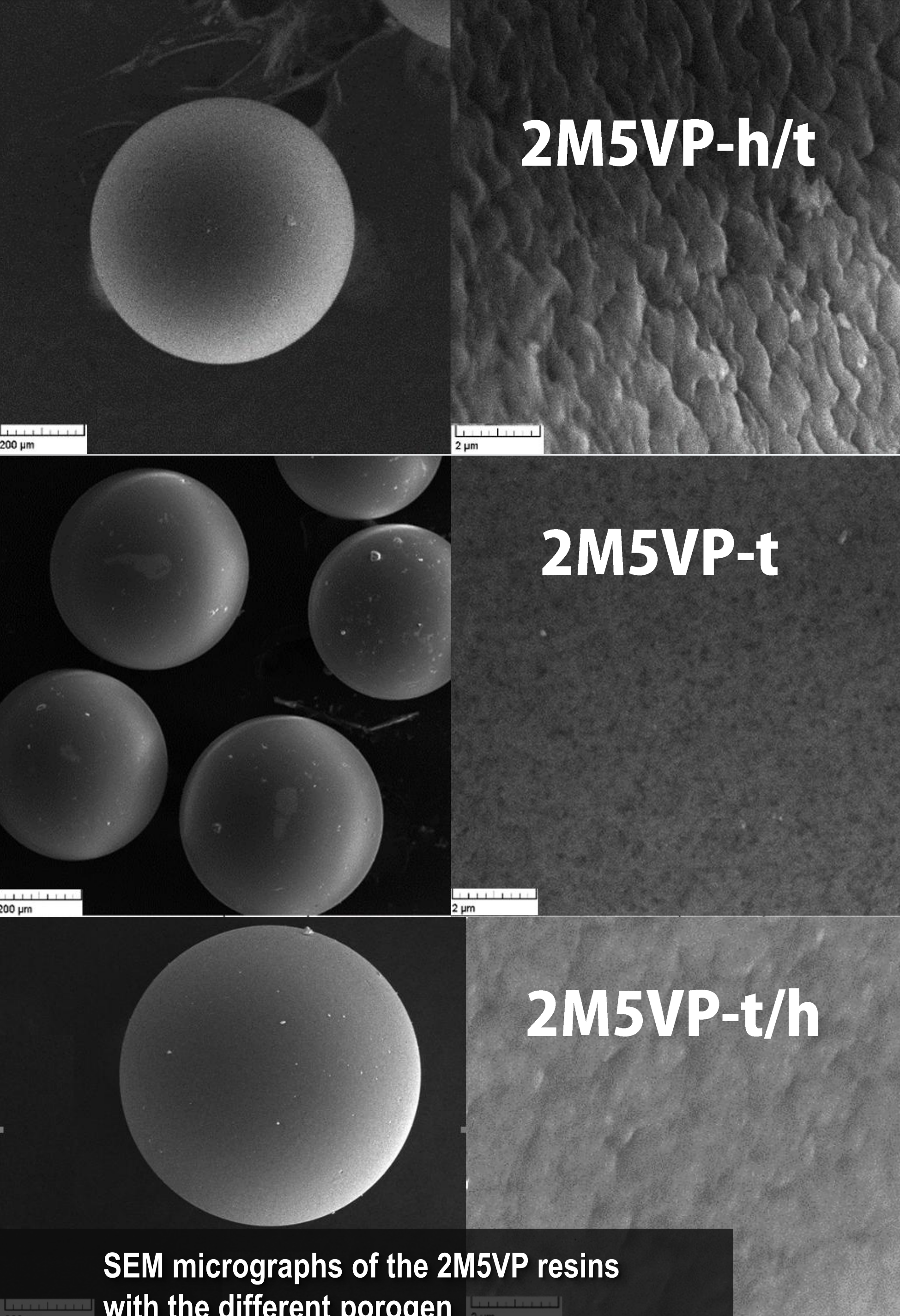
$NiCl_2 \cdot 6H_2O \rightarrow NiCl_2 + 6H_2O\uparrow$ (T = 873 K, fast heating, 10 min)

$NiCl_2 \cdot 2H_2O \rightarrow NiCl_2 + 6H_2O\uparrow$ (T = 473 K, p = $5 \cdot 10^{-3}$ bar, 4 h)

$NiCl_2 + H_2 \quad Ni + 2HCl\uparrow$ (T = 473 K, HCl/H_2 = 1.5, 3 h)

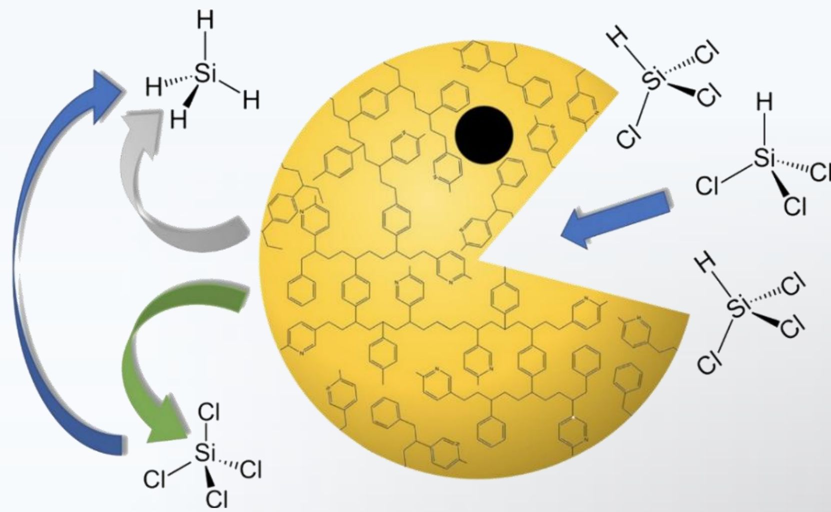
Compound	Flammability	Explosive	Toxicity
$SiCl_4$	1	2	4
$GeCl_4$	1	2	4
$SiHCl_3$	4	2	4
SiH_4	4	3	2
GeH_4	4	3	4

ENERGY SAVING CATALYTIC PROCESSES



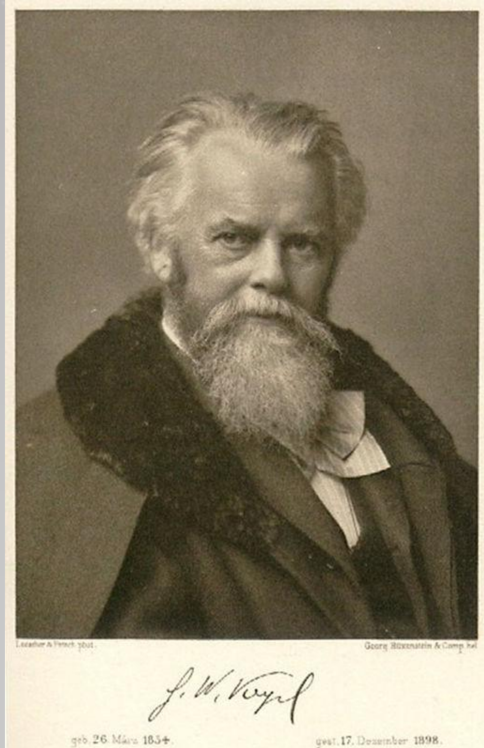
SEM micrographs of the 2M5VP resins with the different porogen

REACTION MECHANISM



CHARACTERISTICS OF THE SYNTHESIZED CATALYST

Symbol	Diluents / (%v/v, Tol/Hep)	Specific area / $m^2 \cdot g^{-1}$	Average pore diameter / nm	Particle average diameter / µm	Exchange capacity / (meq/ml)
2M5VP-t	100/0	8.012	31.862	302	4.5
2M5VP-t/h	90/10	9.043	32.024	338	4.8
2M5VP-h/t	50/50	28.15	80.418	362	5.3



Будучи химиком, Герман Фогель знал, как сделать бомбу! На самом деле большая часть его курса обучения была посвящена тому, как не сделать ее по ошибке…

«Химия занимается веществами, а не телами»

Д.И. Менделеев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impossible

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