R&D Project Management in the Chemical Industry

The following collection of PowerPoint® Charts is intended to further clarify and supplement the relevant specialist publications on the subject matters dealt with. This collection in no way is used for any commercial purposes, but as learning material for students.

Selected sources for in-depth studies of the respective subject matters are given in some lists of references.

The chemical-technical target components listed in the case study tasks, the formulas, deadlines, economic and technical data as well as the data in the "profile boxes" are widely with a practical orientation, but purely fictitious.

They are solely used for a vivid depiction of the methods and as exercise materials.

Congruence with target sets of third parties would be purely coincidental.

Rainer Buerstinghaus

R&D Project Management
in the Chemical Industry

Supplementary Module 01 for Chemists (m/f/d)

Information material *for a case study task.*

New "Ionic Liquids" as Flame-Retardant Electrolytes in Lithium Ion Cells.

Rainer Buerstinghaus

R&D Project Management in the Chemical Industry

Subject Matter	*Physico-Chemical Basics (+ Task for a Case Study).*

New "Ionic Liquids" as Flame-Retardant Electrolytes in Lithium Ion Cells.

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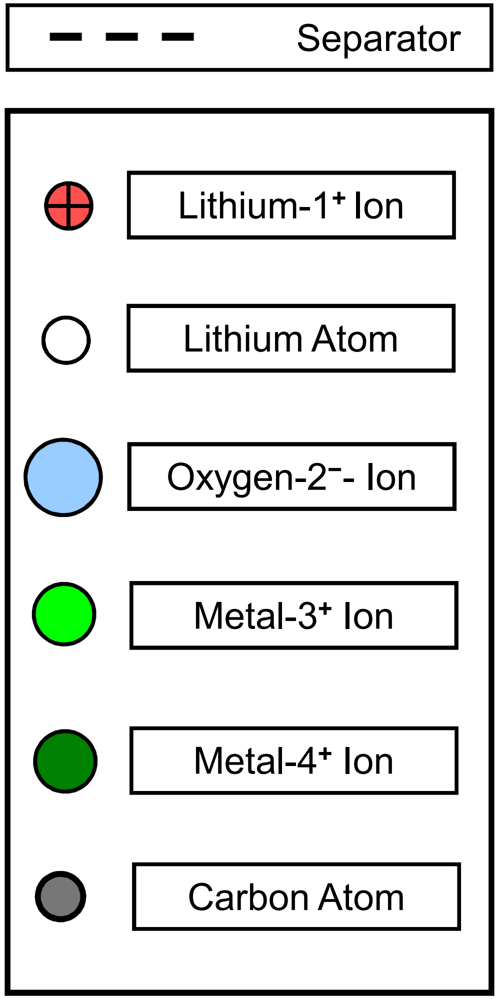
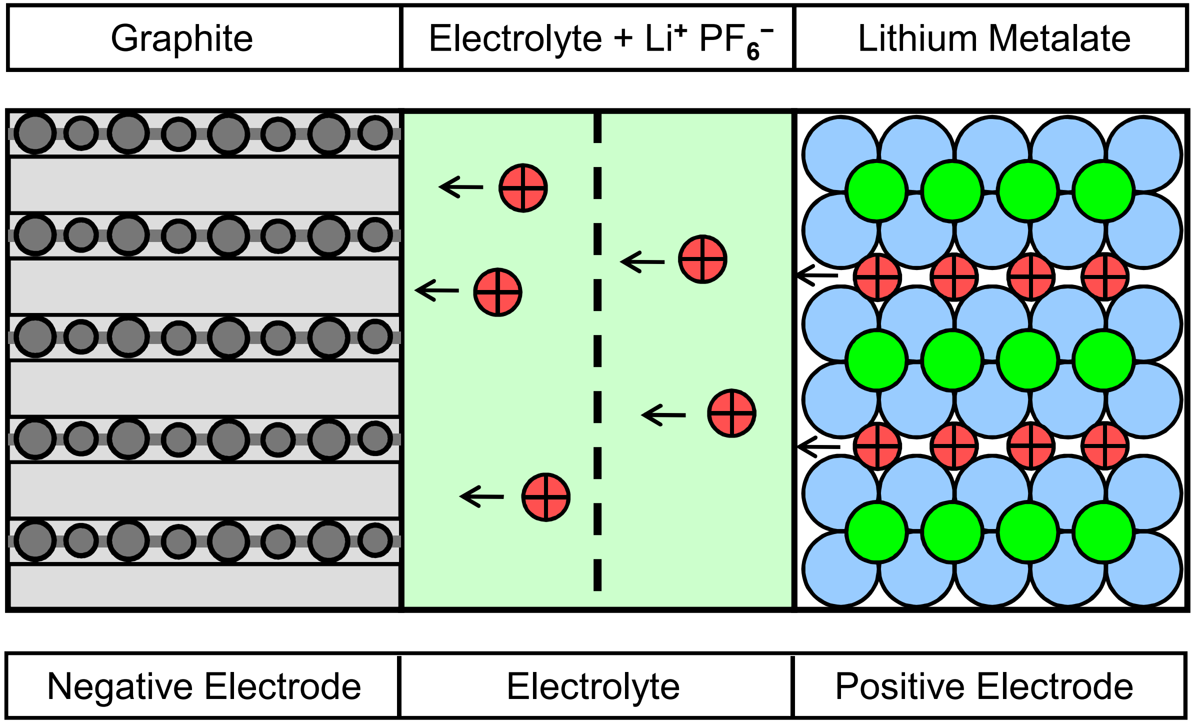
Lithium Ion Cell: Principle of Operation.

Li Ion Cells ($LiMO_2$ / C_n), Start of the Charging Process.





Reaction Equation:

$$Li_{1-x}MO_2 + Li_xC_n \underset{\textbf{Charging}}{\overset{\text{Discharging}}{\rightleftarrows}} Li\,MO_2 + C_n$$

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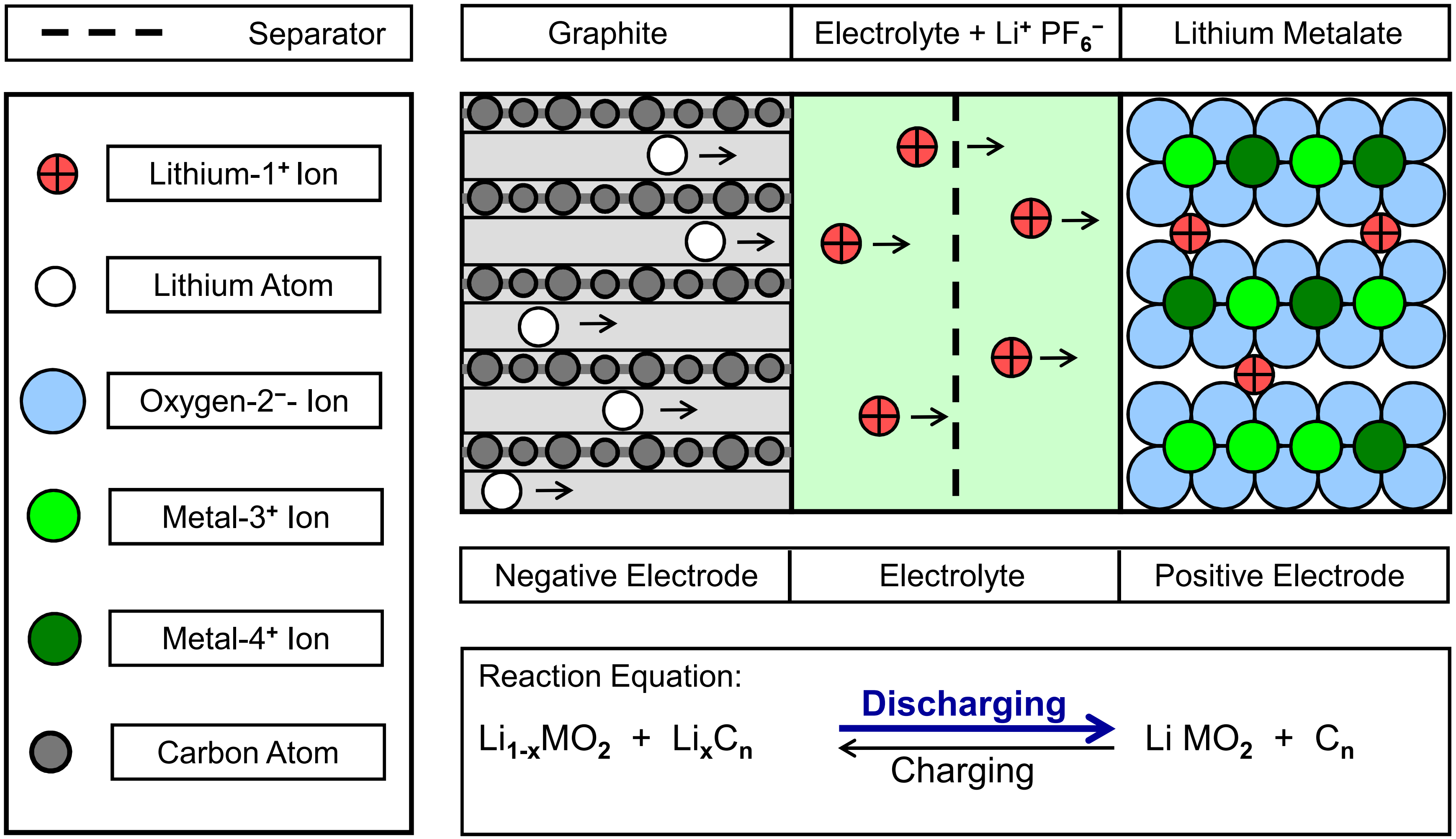
Lithium Ion Cell: Principle of Operation.

Li Ion Cells ($LiMO_2$ / C_n), Start of the Discharging Process.



Reaction Equation:

$$Li_{1-x}MO_2 + Li_xC_n \underset{\text{Charging}}{\overset{\text{Discharging}}{\rightleftharpoons}} Li\,MO_2 + C_n$$

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Lithium Ion Cell: Currently Common Materials.

Substances for the Production of Negative Electrodes ⊝ :

Negatively Charged Active Electrode Materials	Formula	Li-Containing Intercalation Compounds
Graphite	C	LiC_6
Aluminum	Al	LiAl
Antimony	Sb	Li_3Sb
Tungsten Dioxide	WO_2	$LiWO_2$
Tin	Sn	$Li_{22}Sn_5$
Tin Dioxide	SnO_2	Li_xSnO_2
Nanocrystalline Silicon	Si	$Li_{22}Si_5$
Lithium Titanate (2 $Li_2O \cdot 5 TiO_2$)	$Li_4Ti_5O_{12}$	$Li_7Ti_5O_{12}$
Magnetite, Nanoparticul. in CNT	Fe_3O_4 @ CNT	(„$4Li_2O/3Fe$ @ CNT“)

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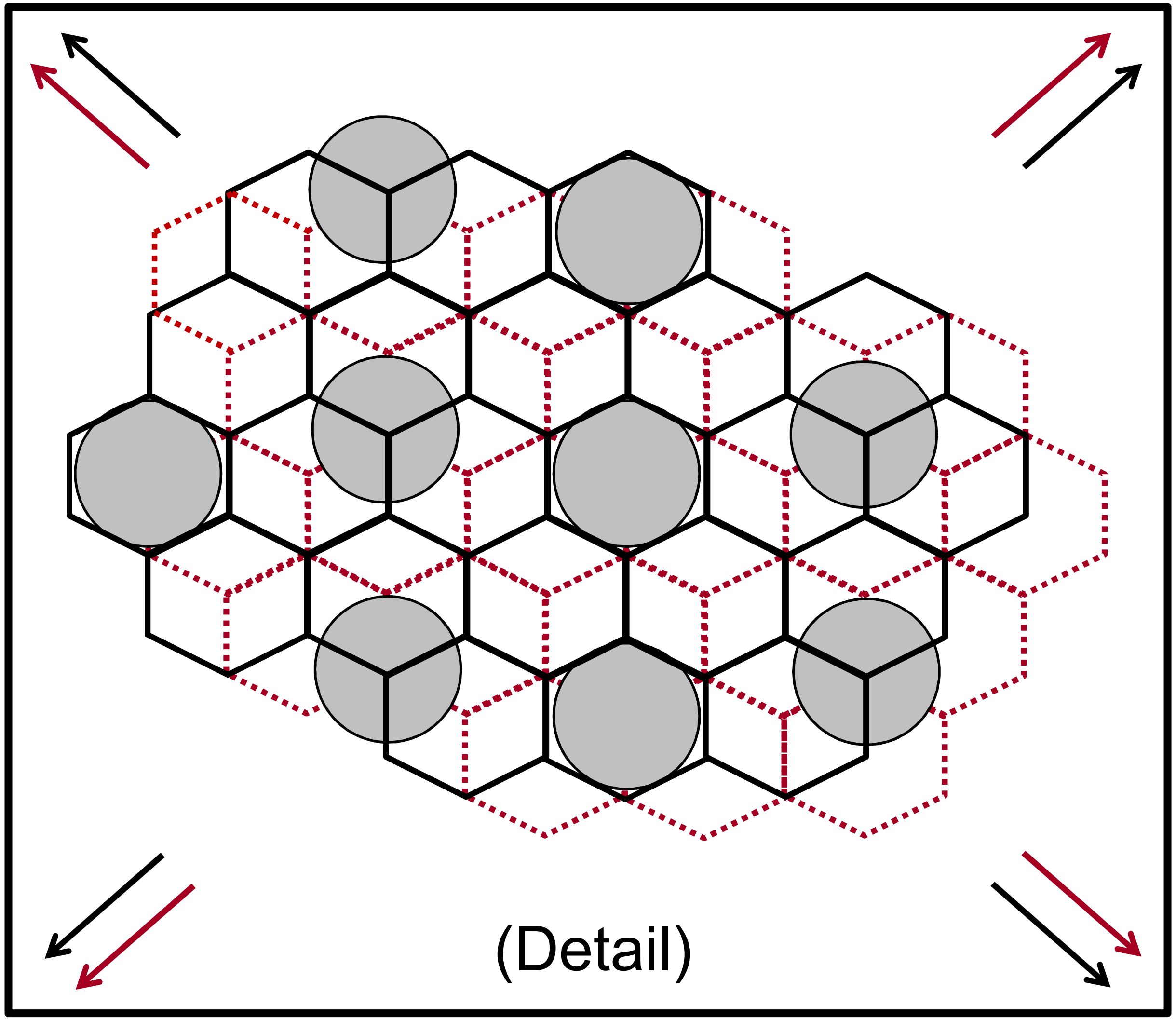
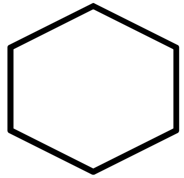
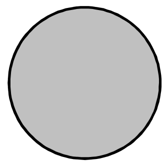
Lithium Ion Cell: Graphite Layer Structure as a "Li Host".

Intercalation of Li in the C-Layer Structure as LiC_6 .

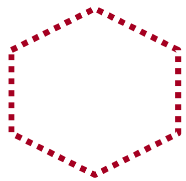




Front Graphene Layer



Lithium Atom



Rearward Graphene Layer

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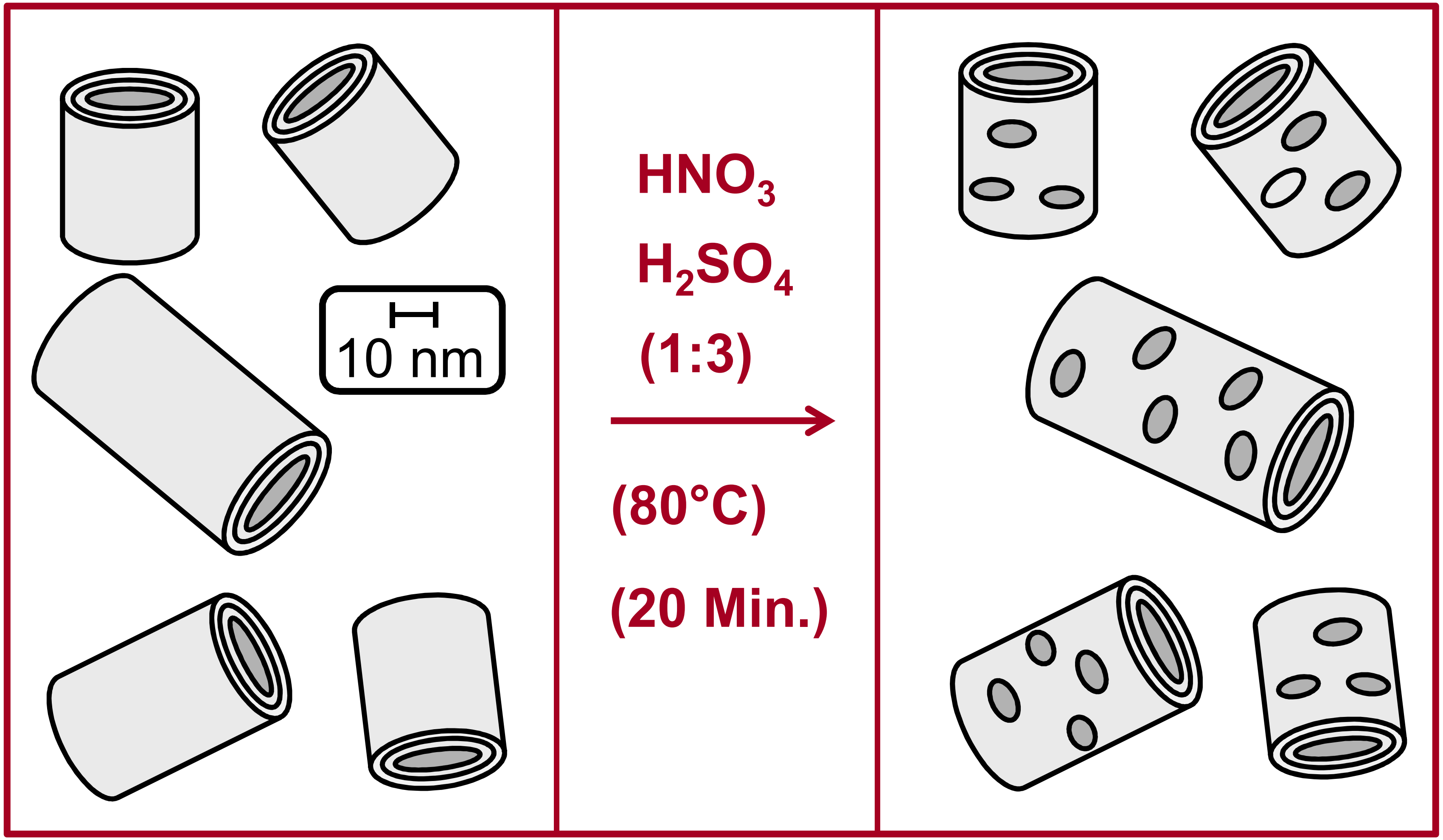
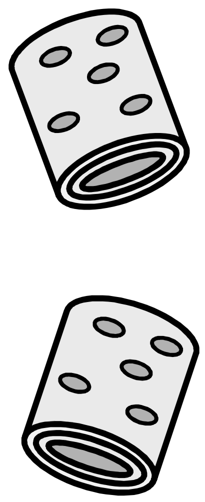
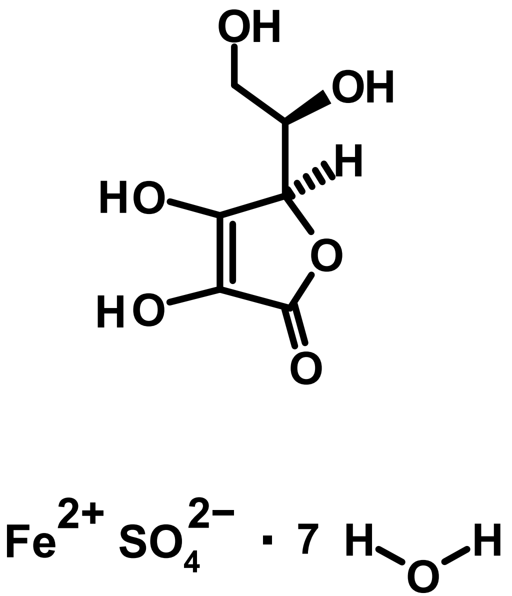
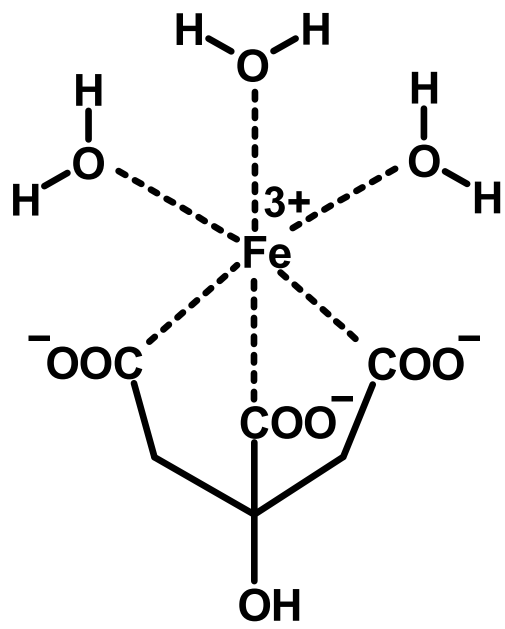
Lithium Ion Cells: Fe_3O_4 @ CNT as a "Li Host".

Preparation of Mesoporous Multi-Wall CNTs.



Lithium Ionen Cells: Fe_3O_4 @ CNT as a "Li Host".

Mesoporous Fe_3O_4 @ CNT via Hydrothermal Synthesis.

	+		+	
"Oxidized" CNTs		Iron-II-Sulphate + Vitamin C (2 Moles)		Iron-III-Citrate (1 Mole)

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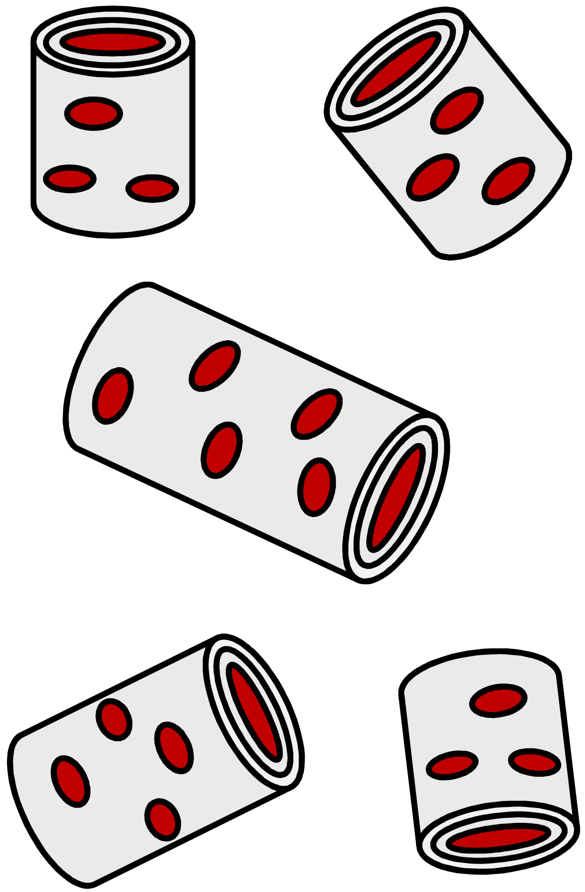
Lithium Ionen Cells: Fe_3O_4 @ CNT as a "Li Host".

Mesoporous Fe_3O_4 @ CNT via Hydrothermal Synthesis.

1. With aqueous NaOH: → pH 10
2. Stainless steel autoclave with Teflon coating: 20 hours at 180 ° C.
3. Separation of Fe_3O_4 @ CNT using a magnet, 5x washing with deionized water.
4. Freeze drying: 24 hours.



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Lithium Ion Cell: Currently Common Materials.

Substances for the Production of Positive Electrodes ⊕ :

Positively Charged Active Electrode Materials	Formula	Redox System
Lithium Cobaltate-(III) $(Li_2O \cdot Co_2O_3)$	$LiCoO_2$	Co^{3+} / Co^{4+}
Lithium Nickelate-(III) $(Li_2O \cdot Ni_2O_3)$	$LiNiO_2$	Ni^{3+} / Ni^{4+}
Lithium Manganate-(III) $(Li_2O \cdot Mn_2O_3)$	$LiMnO_2$	Mn^{3+} / Mn^{4+}
Li-Mn-Spinell $(Li_2O \cdot Mn_2O_3 \cdot 2\ MnO_2)$	$LiMn_2O_4$	Mn^{3+} / Mn^{4+}
Lithium-Nickel-Manganese-Oxide	$LiNi_{0,5}Mn_{1,5}O_4$	$(Mn,Ni)^{3+}/(Mn,Ni)^{4+}$
Lithium-Iron-(III)-Phosphate	$LiFePO_4$	Fe^{2+} / Fe^{3+}

Lithium-Manganese-Nickel-Cobalt-Oxide	$Li\ (Li_{0,20}\ Mn_{0,58}\ Ni_{0,16}\ Co_{0,08})\ O_2$

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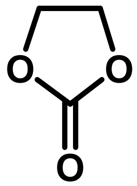
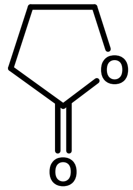
Lithium Ion Cells: Currently Common Electrolytes.

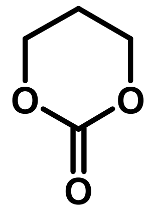
Aprotic and Polar Solvents + Li^+-Conductive Salt.



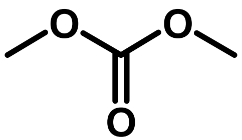
Ethylene Carbonate



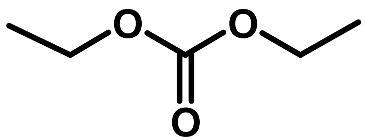
γ-Butyrolactone



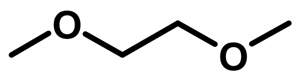
Propylene Carbonate



Dimethyl Carbonate



Diethyl Carbonate



1,2-Dimethoxy Ethane

Risks –

- Low decomposition temperatures
- High Inflammability
- Fire-promoting properties

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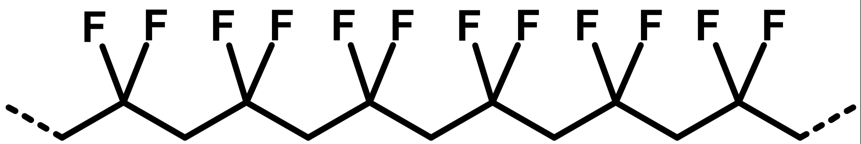
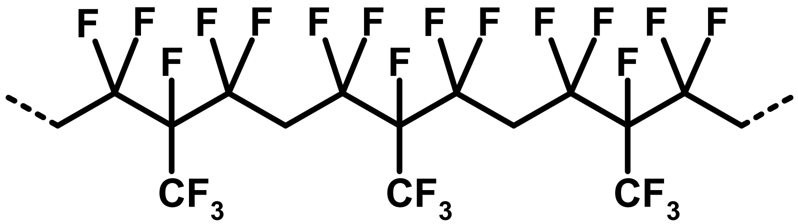
Lithium Ion Cells: Currently Common Electrolytes.

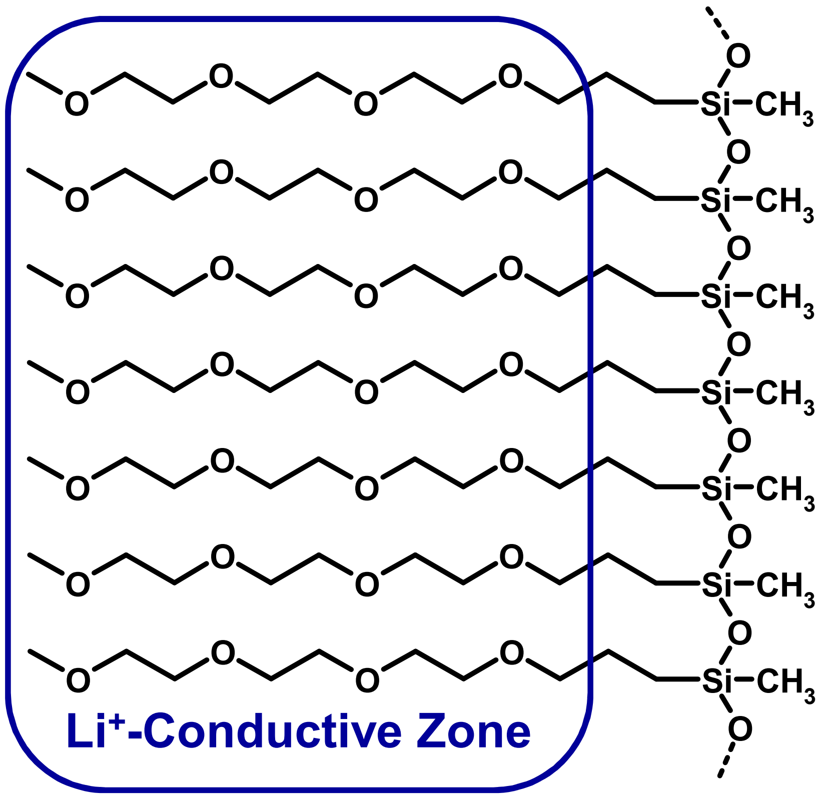
Polymers (+ NMP): Gel-Like Conductive Materials + Li^+-Salts.



Polyvinylidene fluoride (PVDF) is swollen or gelled with NMP (N-Methyl-pyrrolidone).



Vinylidene fluoride – hexafluoro-propene copolymer (PVDF-HFP Copolymer), swollen with NMP.



Ether-modified polysiloxanes as Li^+ -conductive blends for semi-IPN (IPN: Interpenetrating Network).

Ionic Liquids: General Definition.

Ionic Liquid: → Organic molten salt with a melting point below 100°C.

- It consists exclusively of ions.
- It always contains an organic cation.
- It contains an organic, inorganic or organometallic anion.

Ionic Liquids: Chemical and Physical Properties.

- They have electrical conductivities σ of up to 2,50 $S \cdot m^{-1}$.
- They show a very wide range of liquid condition up to 400 units on the Celsius scale.
- In contrast to inorganic "salt melts", they are of low-viscosity (η ≈ 0,02 Pa·s, T = 25°C).
- In contrast to inorganic "salt melts", they do not have any corrosive effect.
- In pure melts, they do not form H^+-bridges.

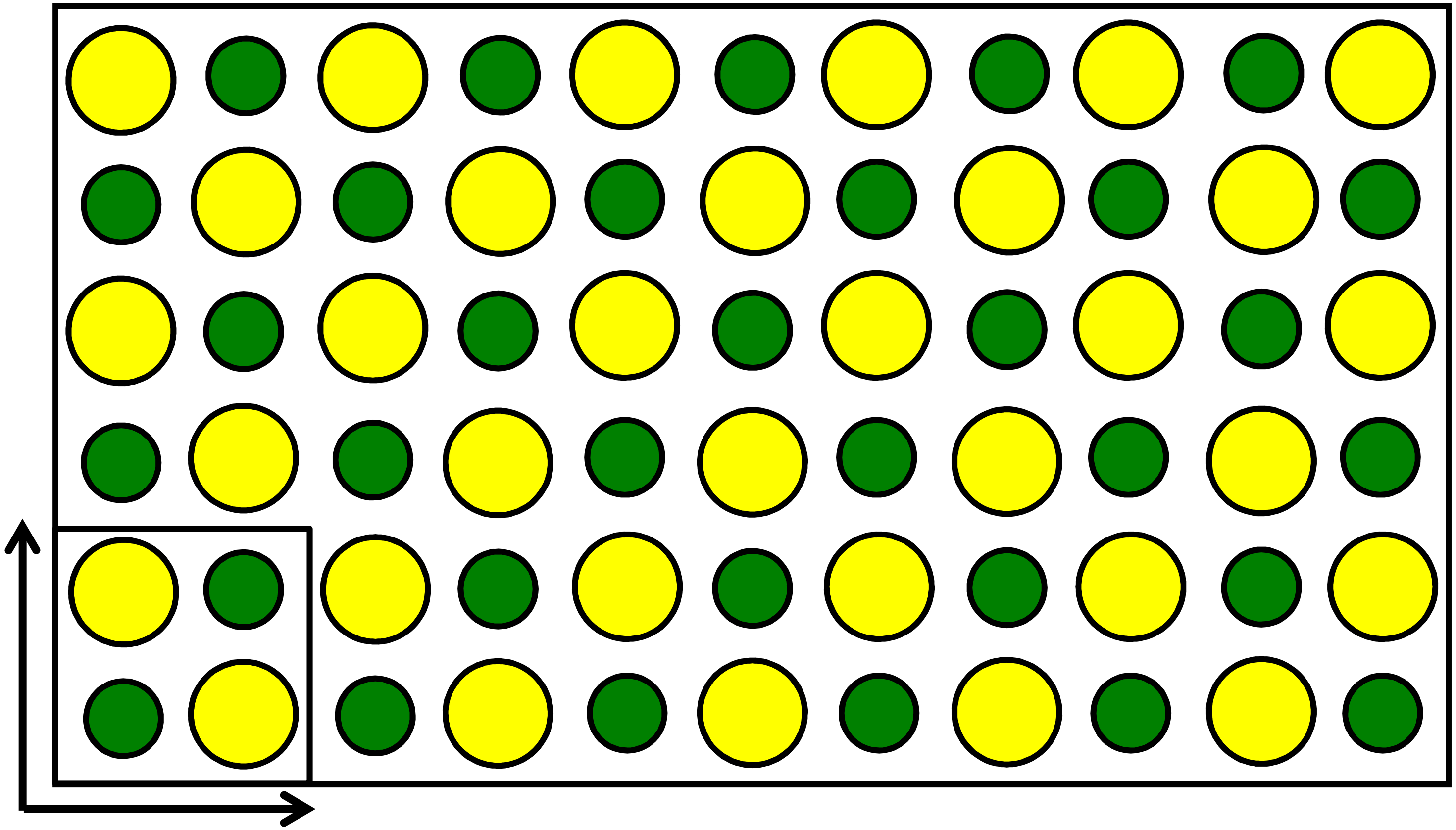
Ionic Liquids: Chemical and Physical Properties.

- They have a vanishingly low vapor pressure below the temperature of their decomposition (T <300°C).
- They are flame-retardant and hardly flammable.
- They show good oxidative and electrochemical stabilities.
- By specifically selecting a cation-anion combination, they can be equipped with the desired physical and chemical properties **("Designer Solvents")**.

Crystalline Salt Consisting of Ions.

Long-Range Order →

For All Single Ions: Potential Energy > Kinetic Energy.



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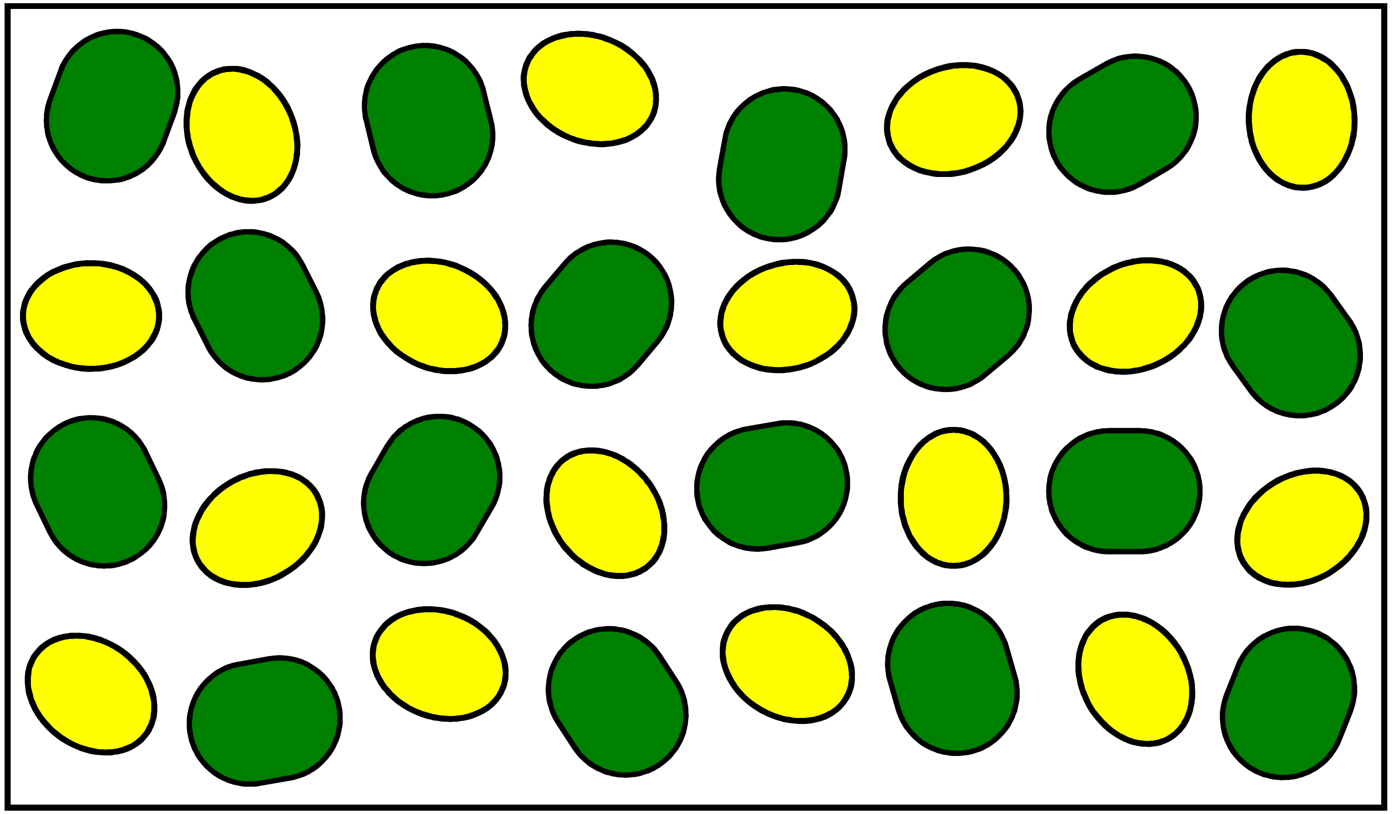
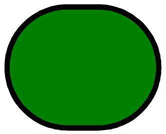
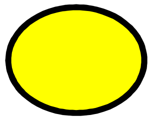
Ionic Liquid: Liquid Consisting of Ions.

Near-Range Order →
For All Single Ions: Potential Energy ≈ Kinetic Energy.



 → Cation

 → Anion

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Near-Range Order ⟶

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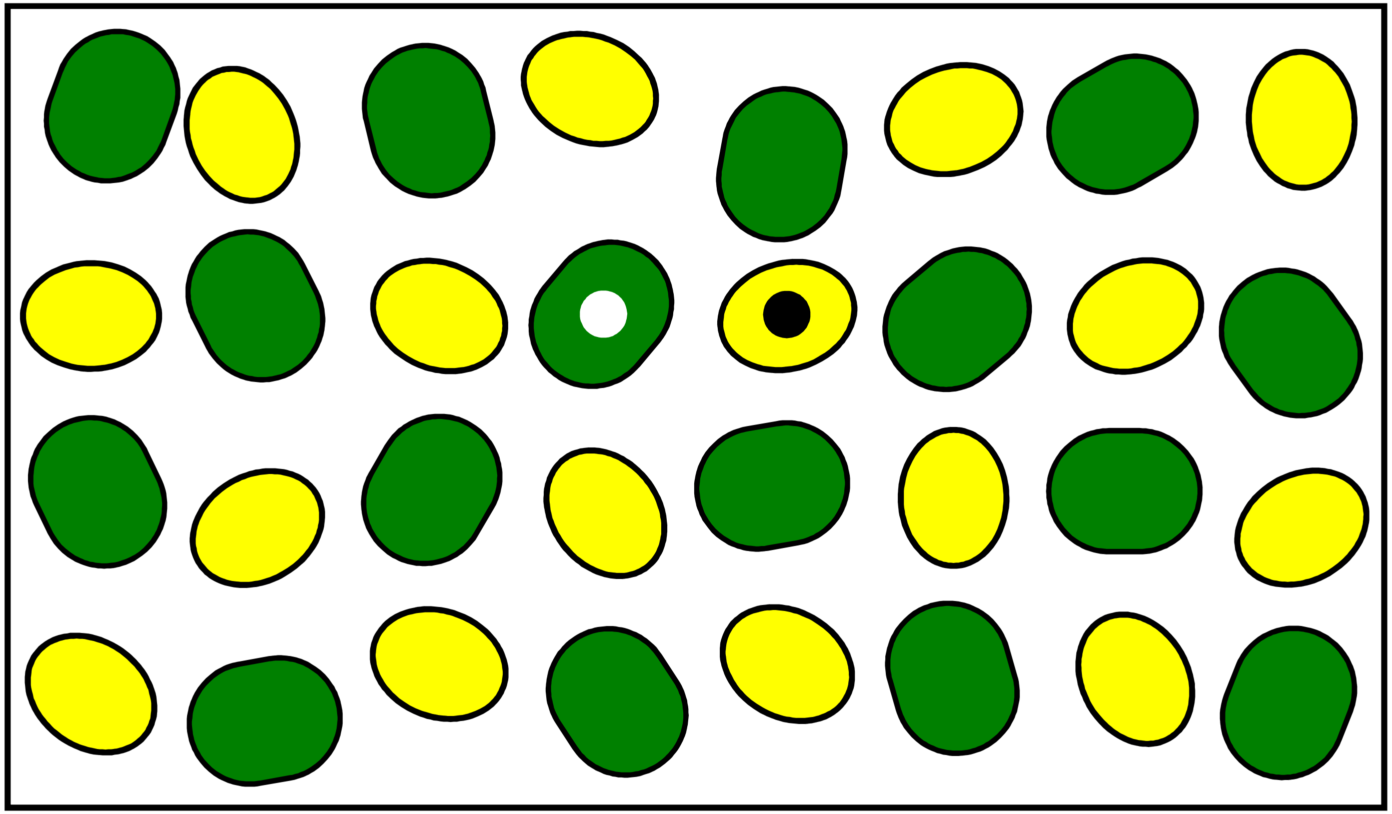
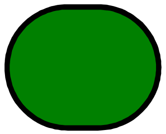
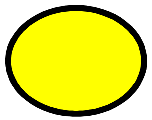


 ⟶ Cation

 ⟶ Anion

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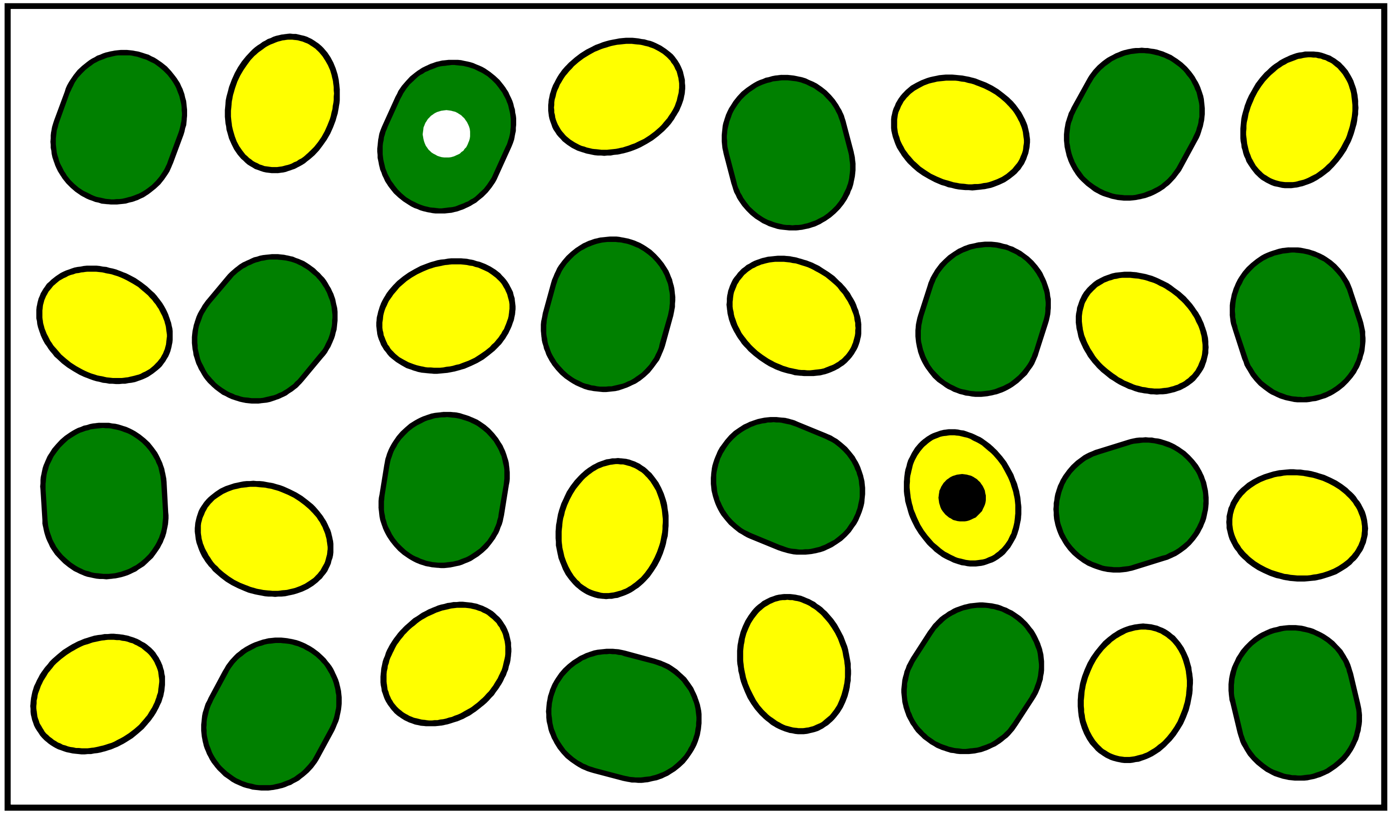

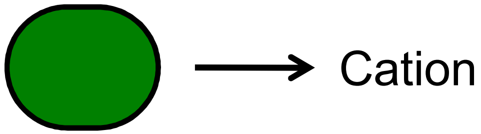

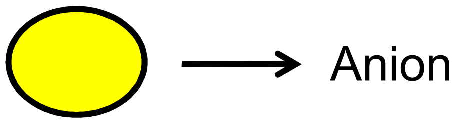

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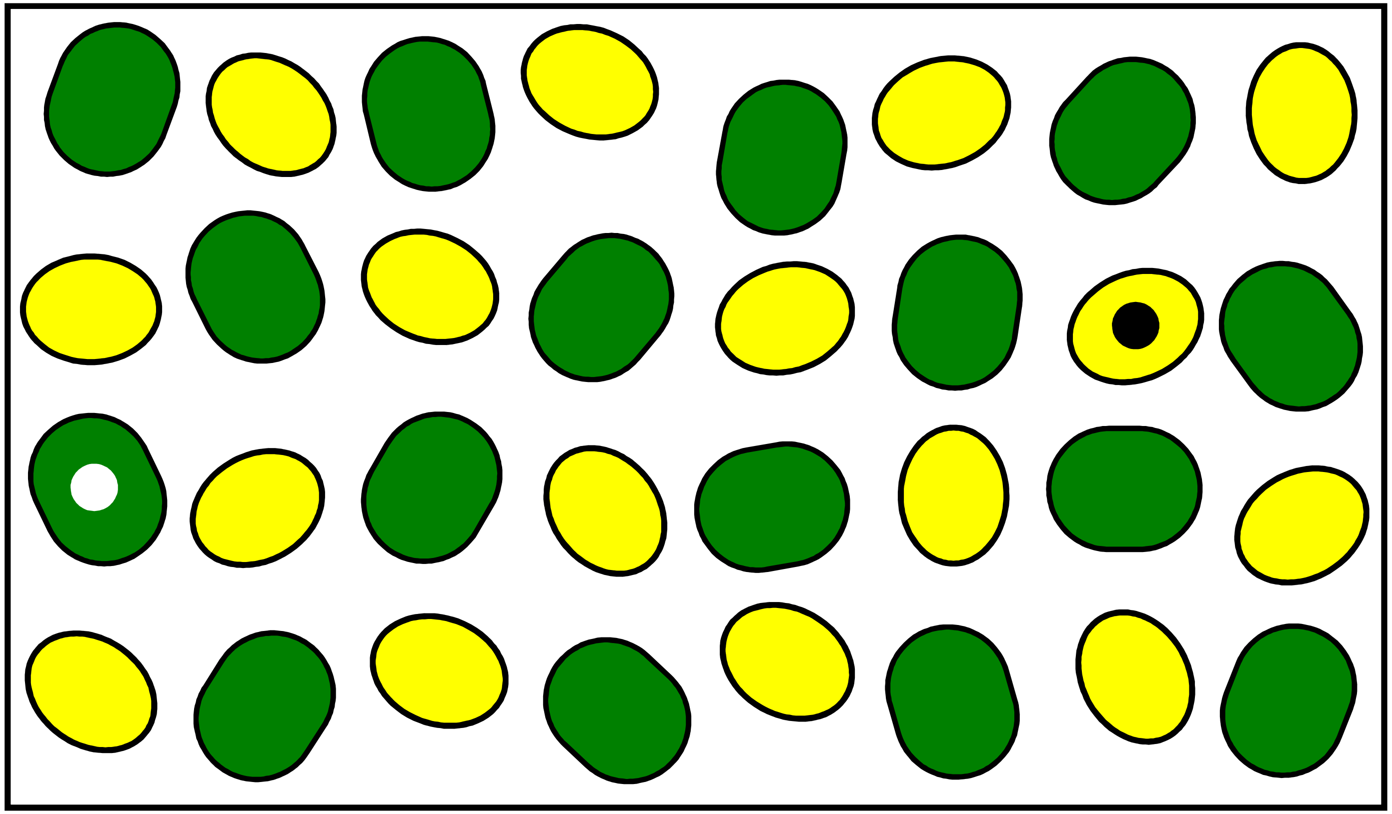

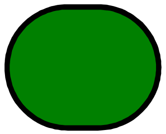

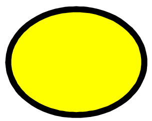

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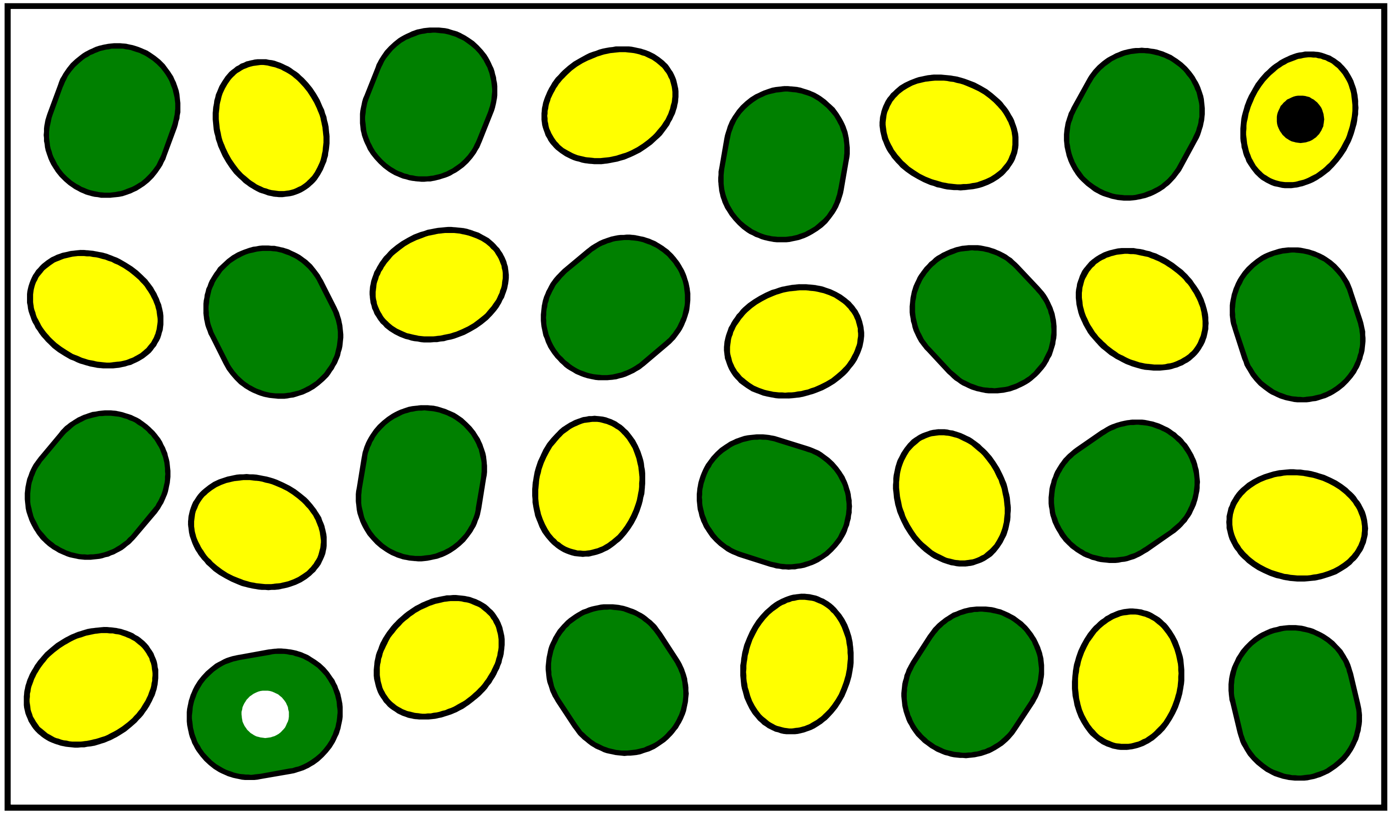
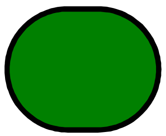
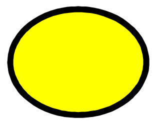


 → Cation

 → Anion

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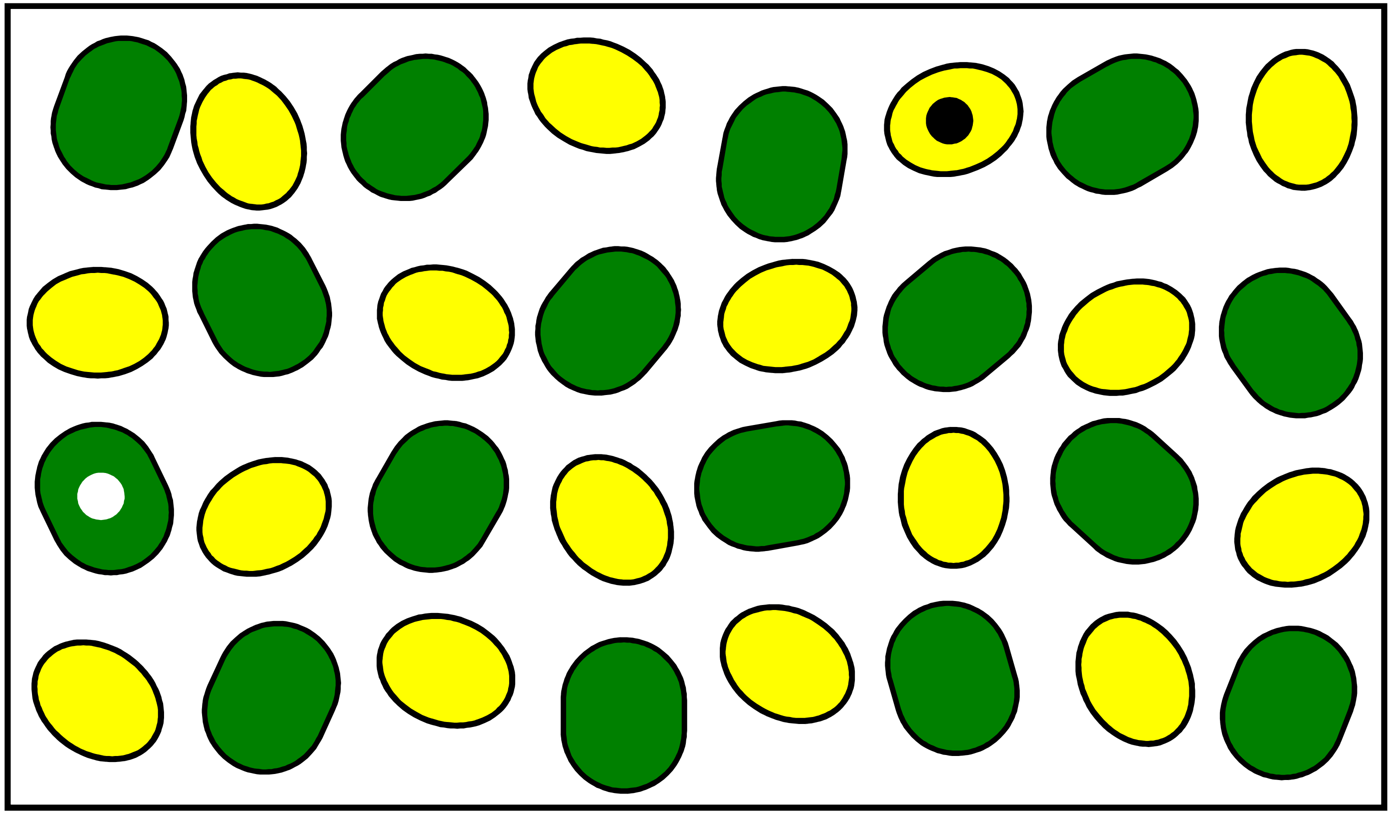
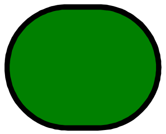
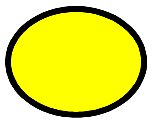


 → Cation

 → Anion

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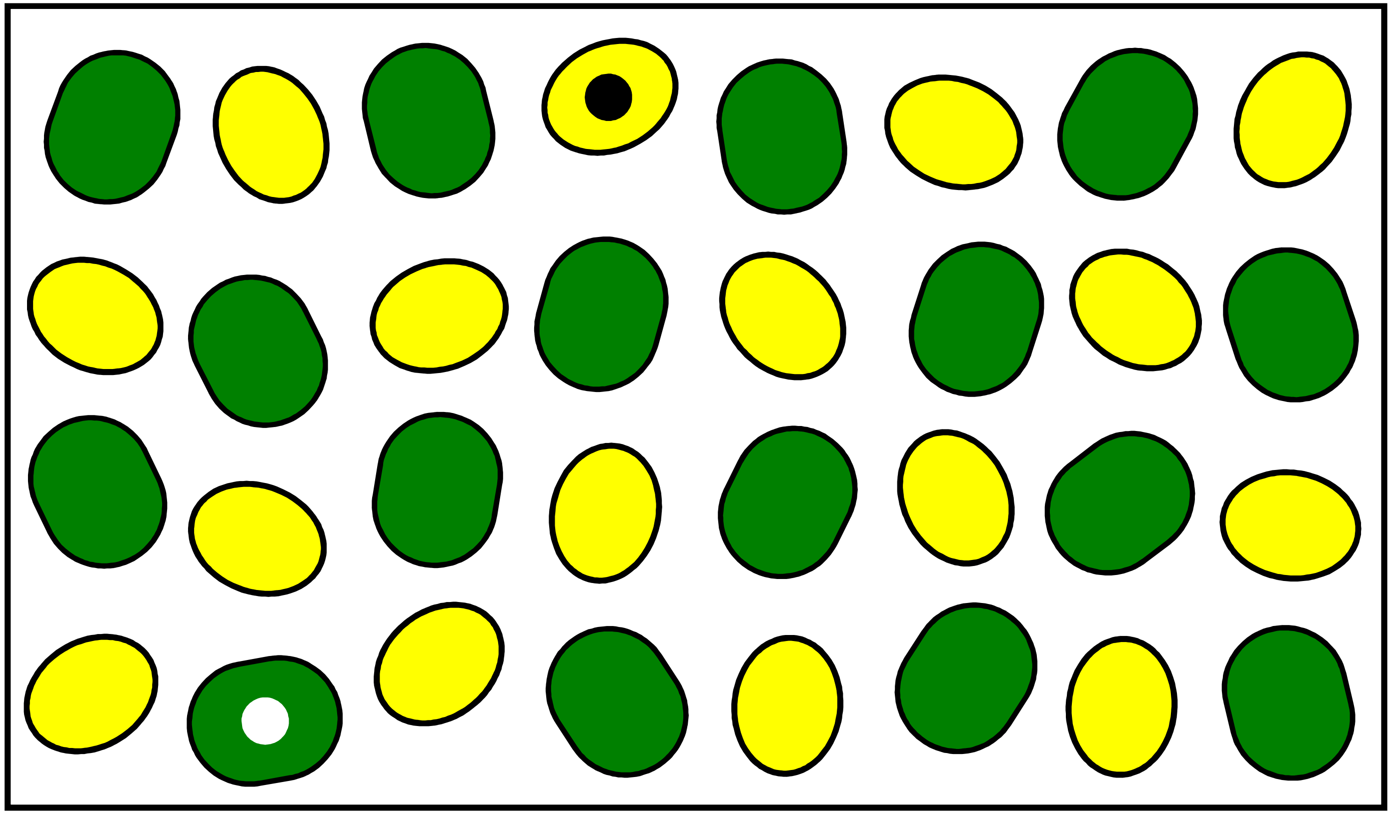
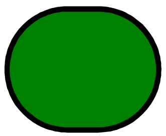
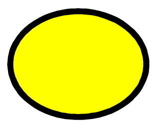


 → Cation

 → Anion

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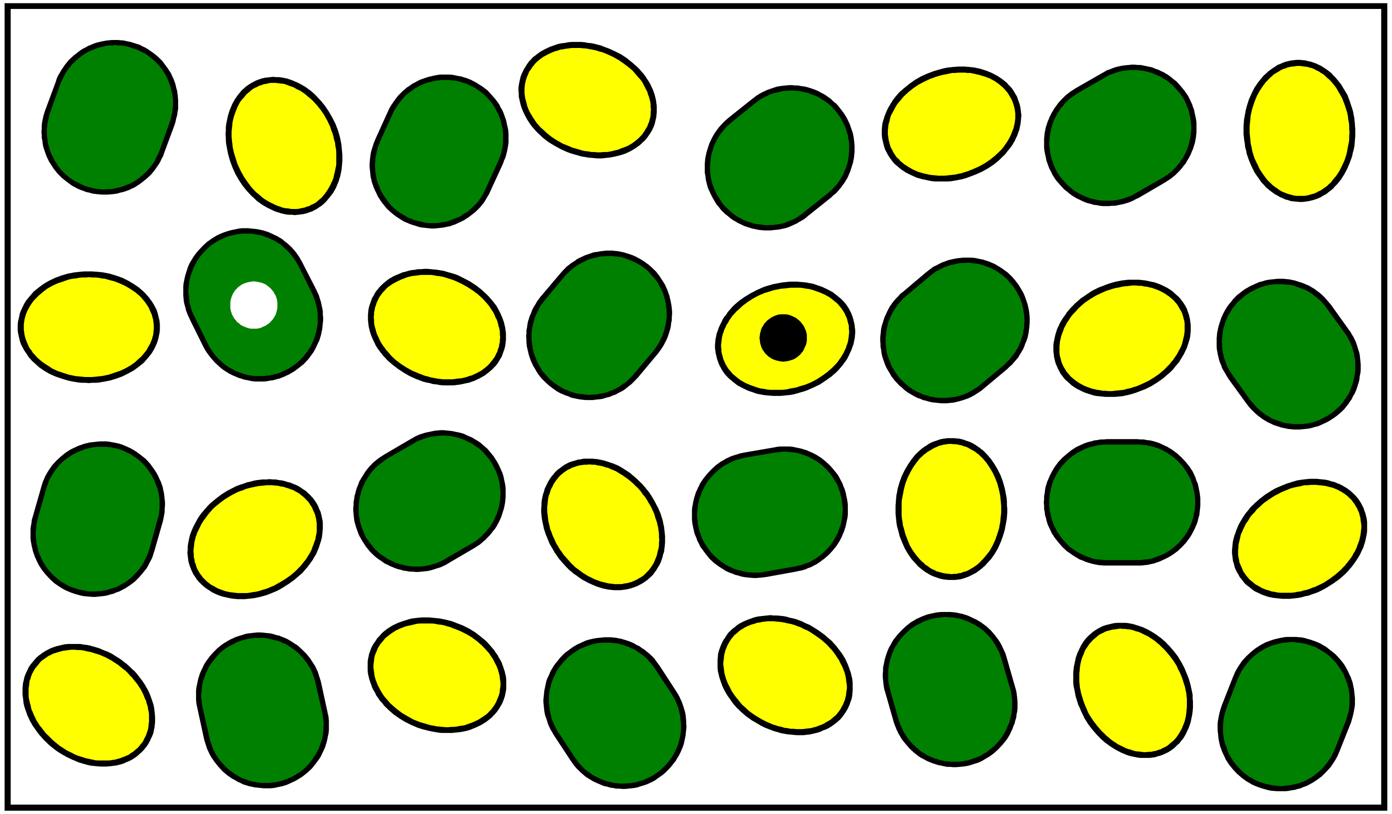

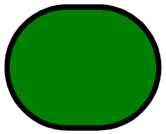

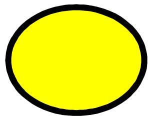

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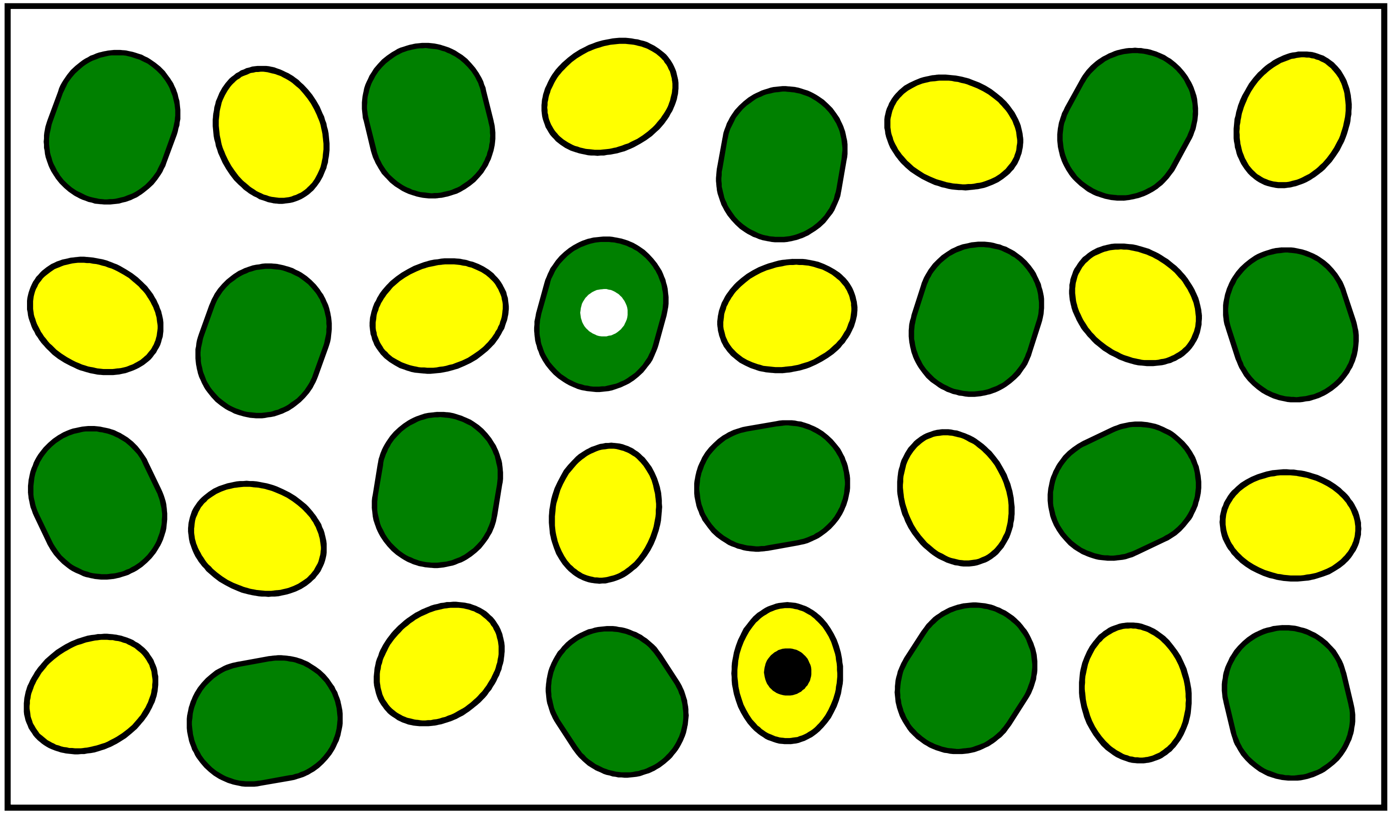
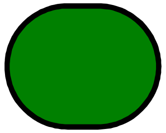
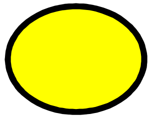


 → Cation

 → Anion

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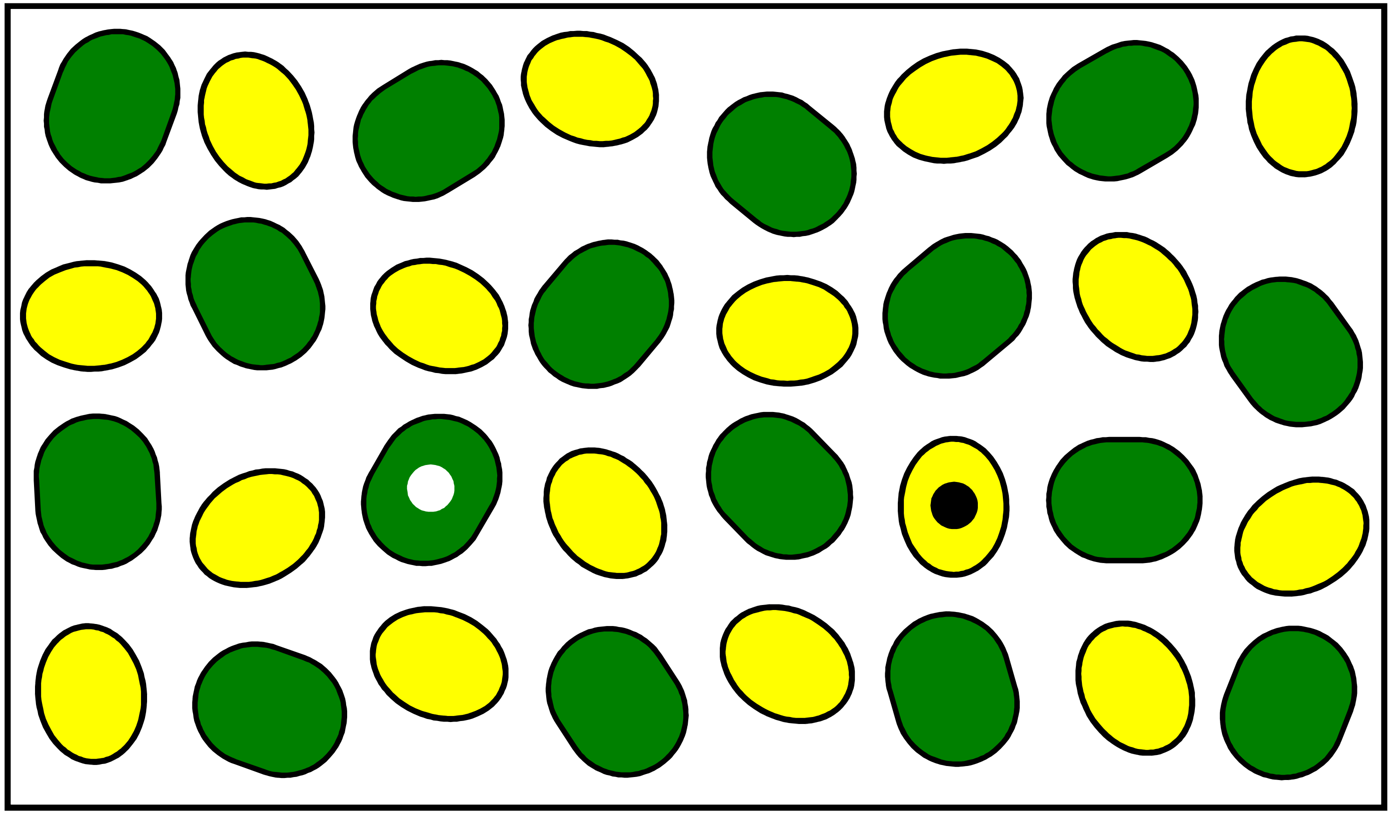

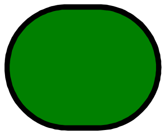

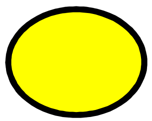

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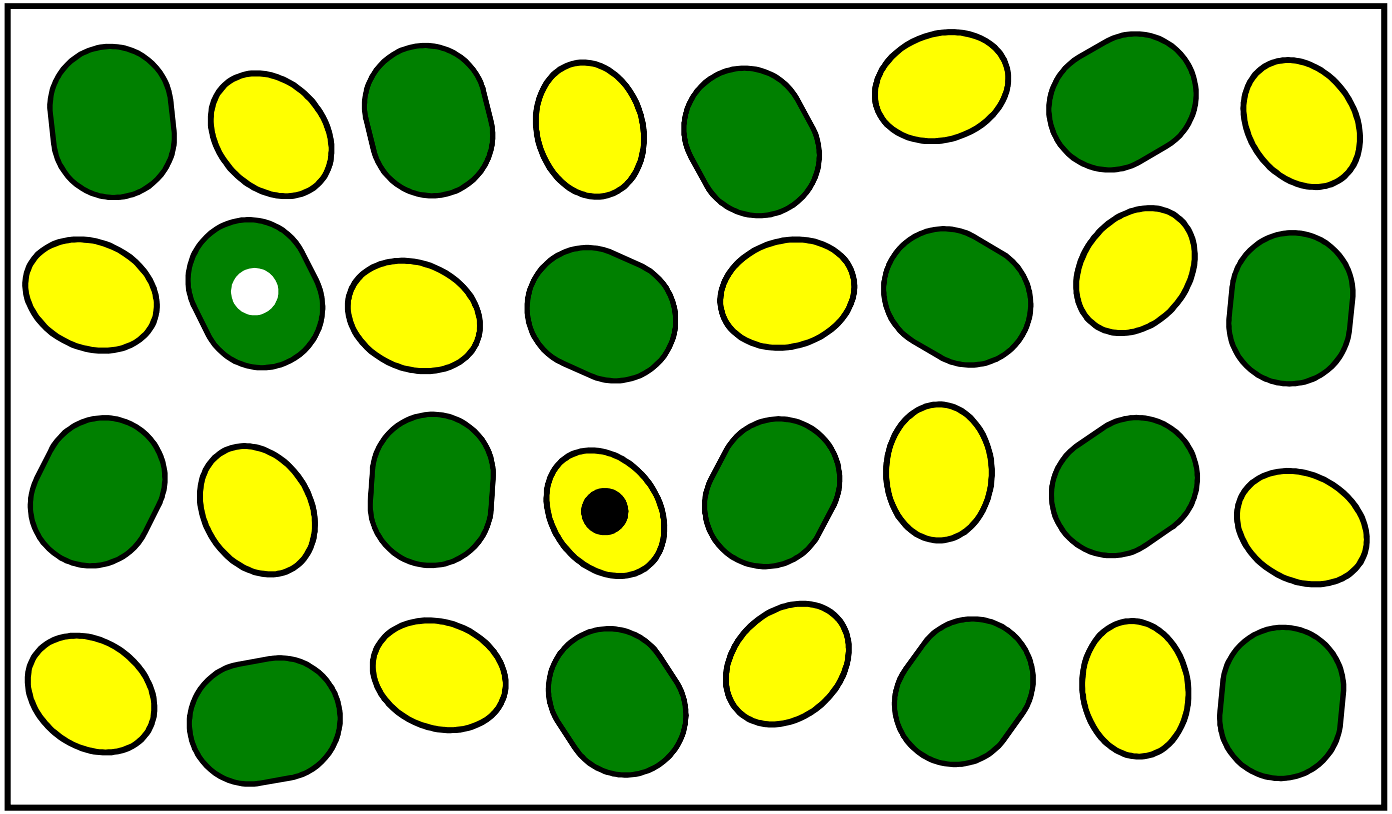
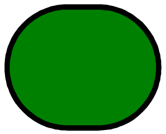
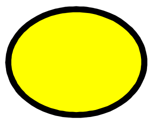


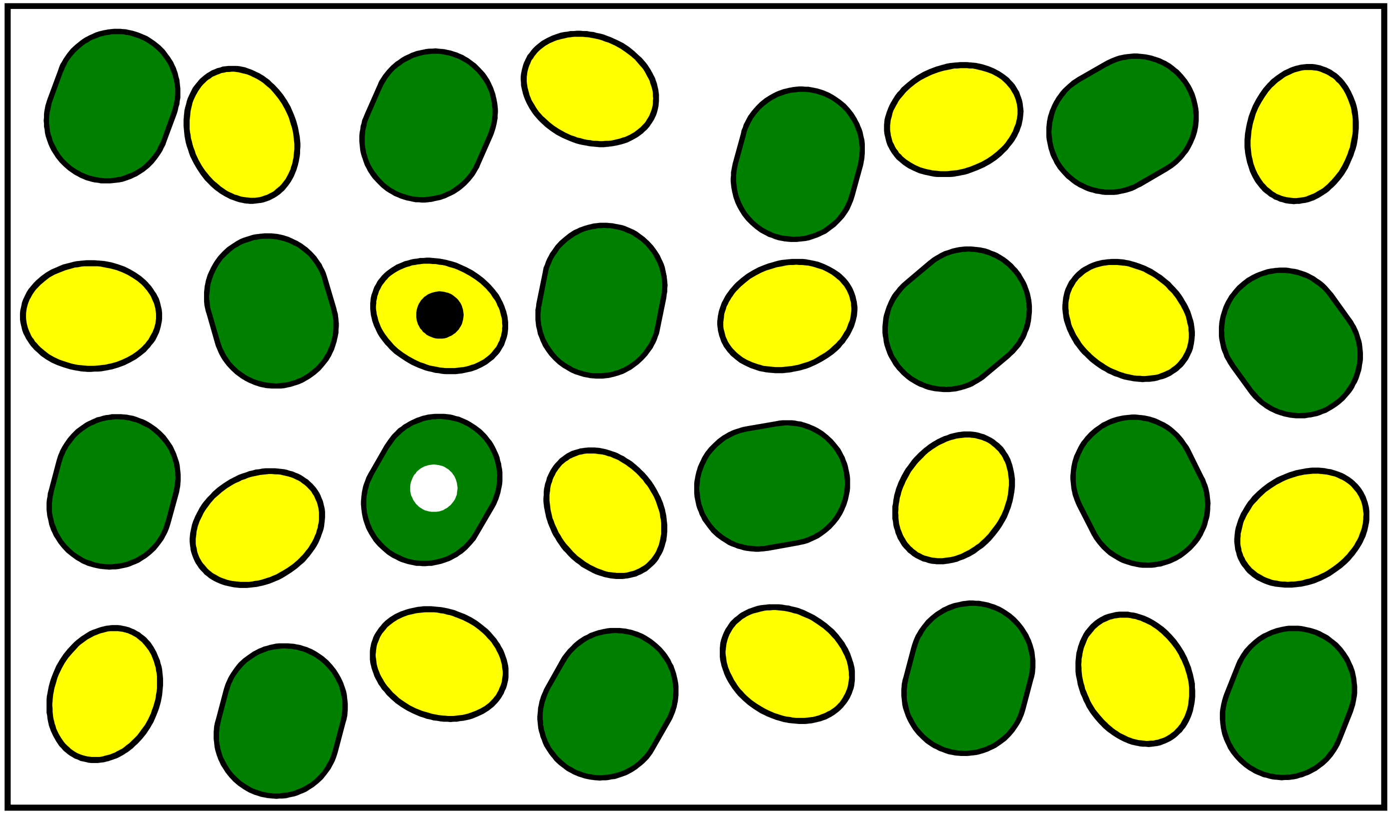
 → Cation

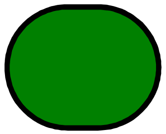
 → Anion

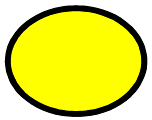
Rainer Buerstinghaus

Ionic Liquid: Liquid Consisting of Ions.

Near-Range Order →
For All Single Ions: Potential Energy ≈ Kinetic Energy.



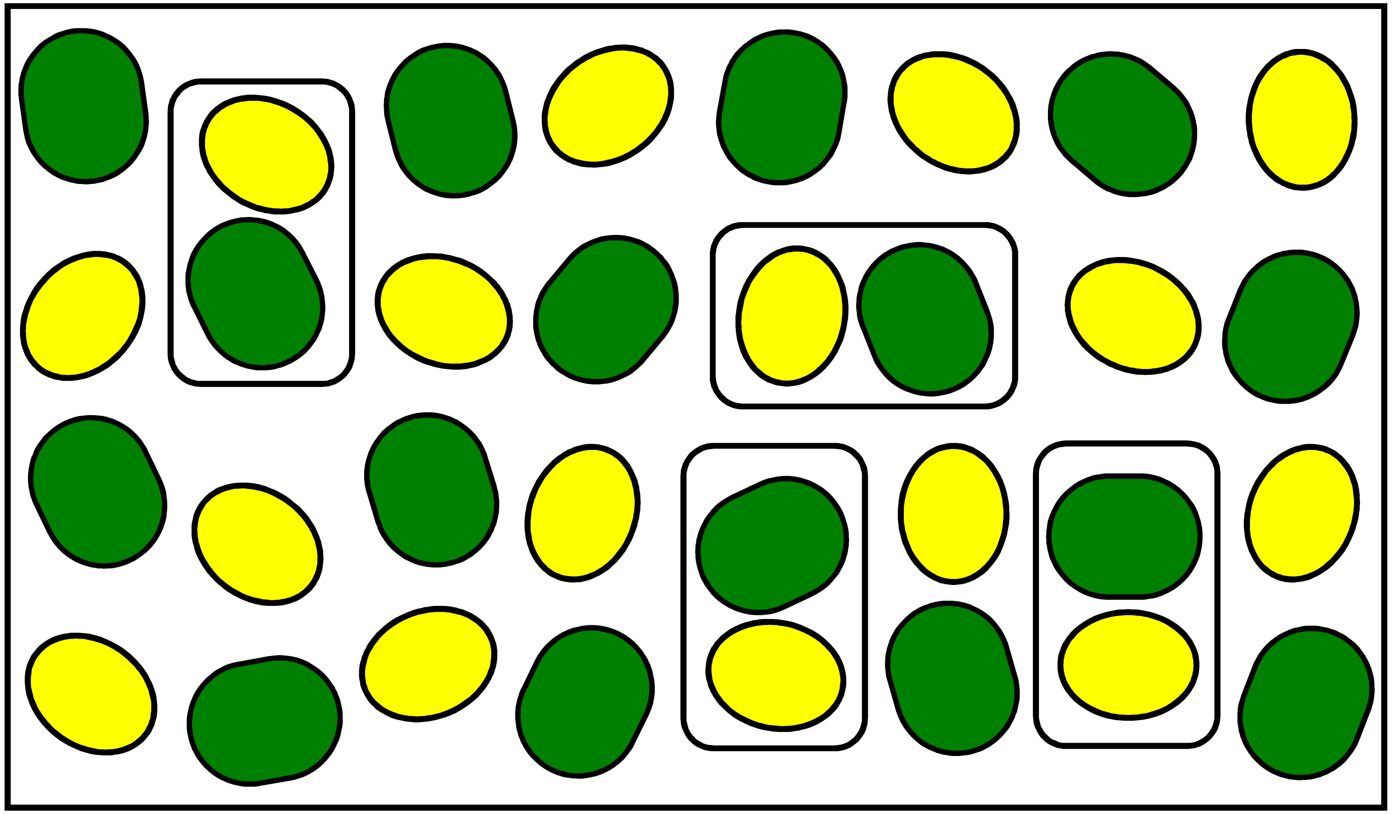
 → Cation

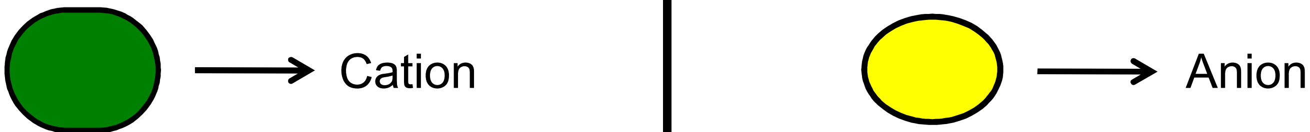
 → Anion

Rainer Buerstinghaus

Ionic Liquid: Liquid Consisting of Ions.

Near-Range Order: Fluctuating Formation of Ion Pairs.
Detection by H-NMR and FT-IR Spectroscopy.





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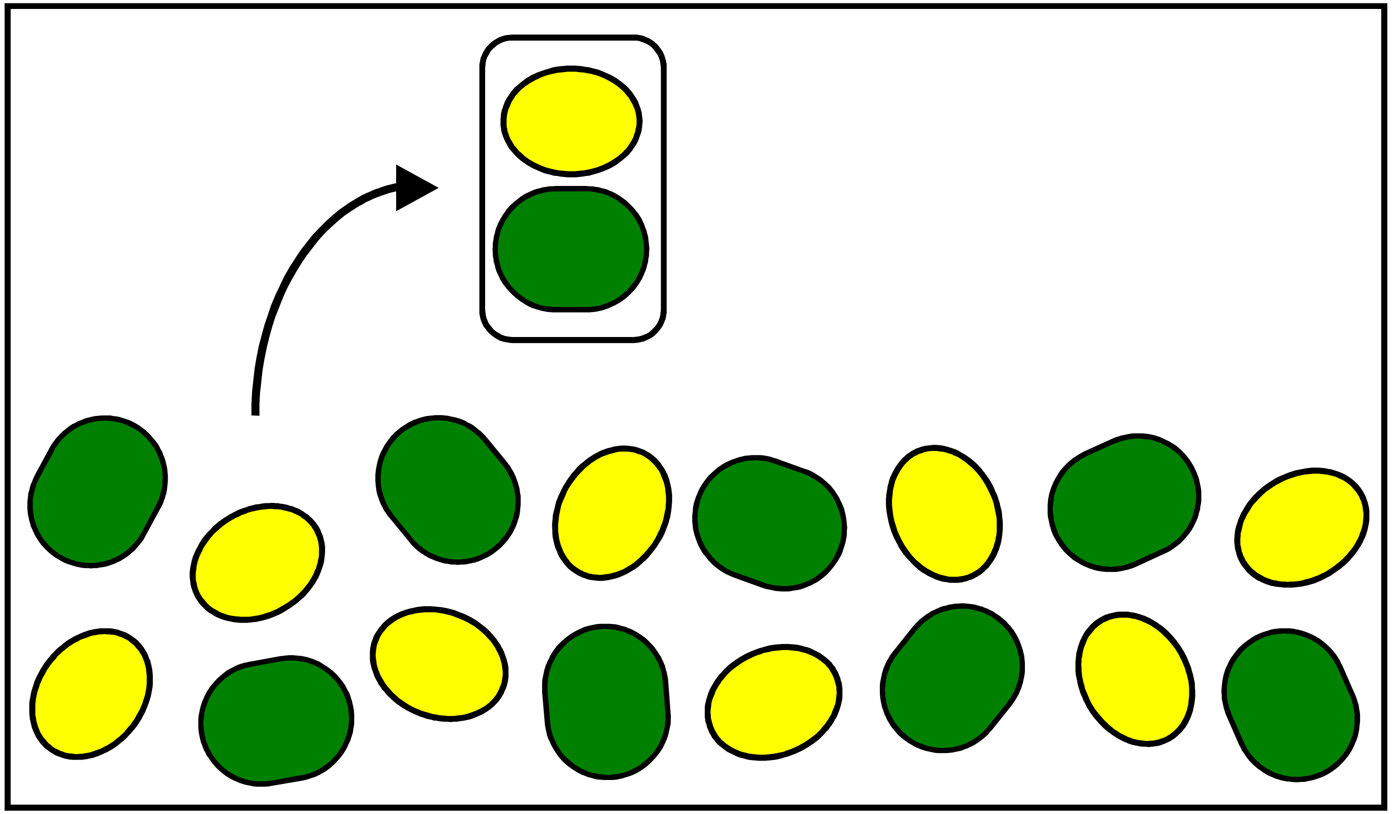
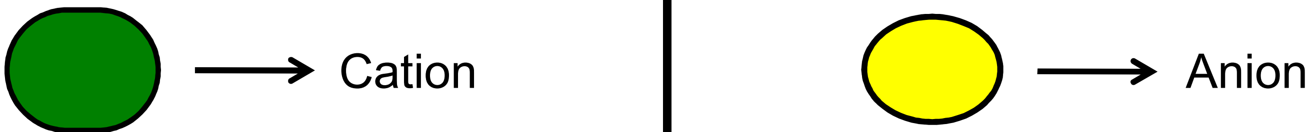
Ionic Liquid: Liquid Consisting of Ions.

Formation of an "Ion Pair Gas" in an Ultra-High Vacuum; Detection by Electrospray MS (Armstrong 2007).





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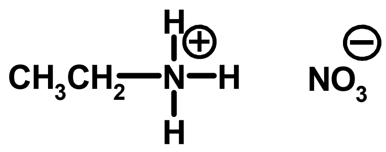
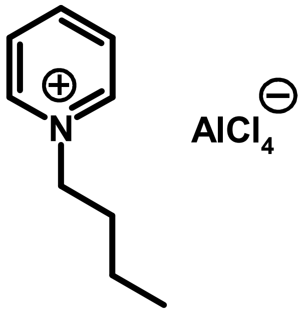
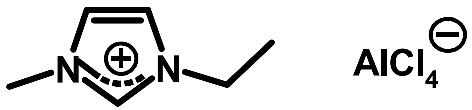
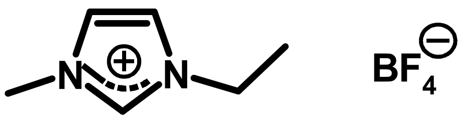
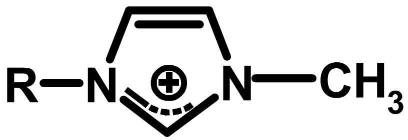
New "Ionic Liquids" as Flame-Retardant Electrolytes

Ionic Liquids: The History of Their Discovery.

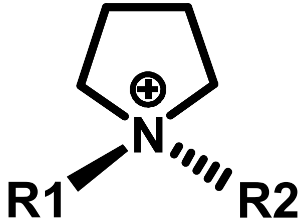
	Paul Walden 1914 Fp.: 13-14°C
	Robert A. Osteryoung 1978 Electrolyte for metal deposition ("Plating").
	Kenneth R. Seddon1983 Solvent for chemical reactions.
	Michael J. Zaworotko, John.S. Wilkes, 1992 Hydrolysis-stable ionic liquids.

New "Ionic Liquids" as Flame-Retardant Electrolytes

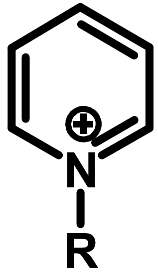
Ionic Liquids: Typical Organic Cations.



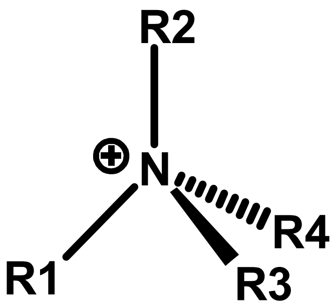
1-Alkyl-3-Methyl-Imidazolium



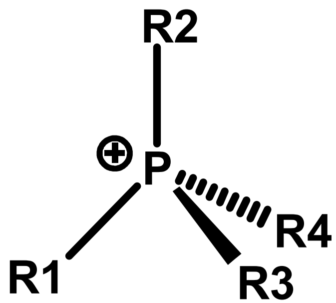
N,N-Dialkyl Pyrrolidinium



Alkyl Pyridinium



Tetraalkyl Ammonium



Tetraalkyl Phosphonium

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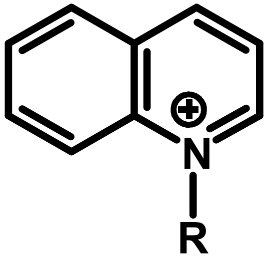
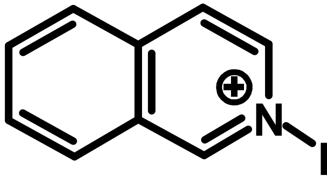
New "Ionic Liquids" as Flame-Retardant Electrolytes

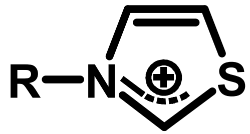
Ionic Liquids: Typical Organic Cations.



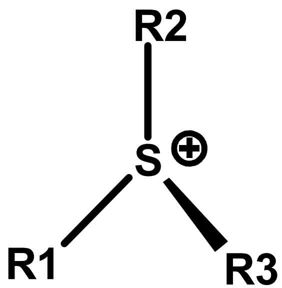
1-Alkyl-Chinolinium



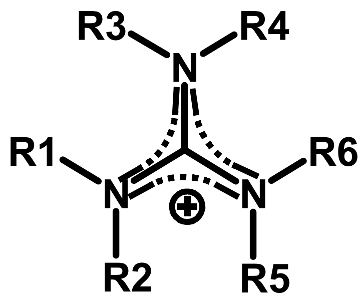
1-Alkyl-Isochinolinium



1-Alkyl-Thiazolium



Trialkyl Sulfonium



Hexaalkyl Guanidinium

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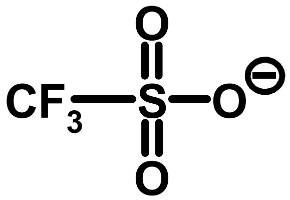
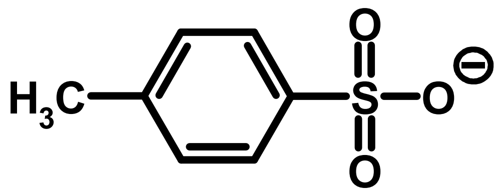
New "Ionic Liquids" as Flame-Retardant Electrolytes

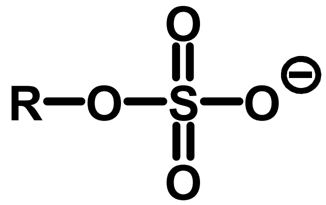
Ionic Liquids: Typical Organic Anions.



Trifluormethyl Sulfonate



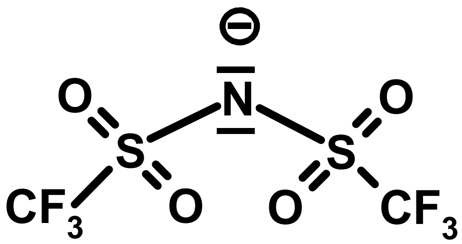
Tosylate



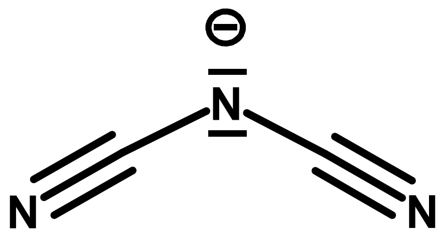
Alkyl Sulfate

$CH_3COO^{\ominus}$

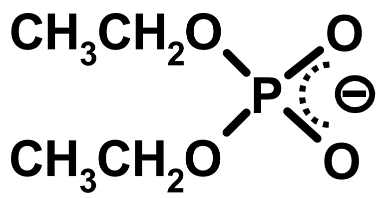
Acetat



Bis(Trifluormethylsulfonyl)amide



Dicyanamide



Dialkyl Phosphate

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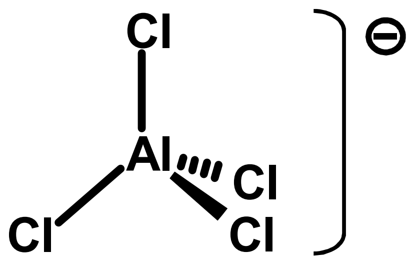
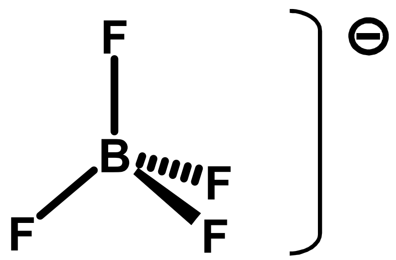
New "Ionic Liquids" as Flame-Retardant Electrolytes

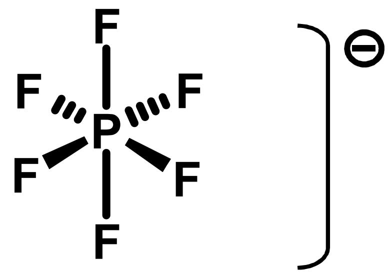
Ionic Liquids: Typical Inorganic Anions.



Tetrachloroaluminate



Tetrafluoroborate



Hexafluorophosphate

$Cl^{\ominus}$	$Br^{\ominus}$	$J^{\ominus}$	$J_3^{\ominus}$	$NO_3^{\ominus}$
Chloride	Bromide	Jodide	Trijodide	Nitrate
$NO_2^{\ominus}$	$NCS^{\ominus}$	$HSO_4^{\ominus}$	$SbF_6^{\ominus}$	$TaF_6^{\ominus}$
Nitrite	Thiocyanate	Hydrogen-sulfate	Hexafluoro-antimonate	Hexafluoro-tantalate

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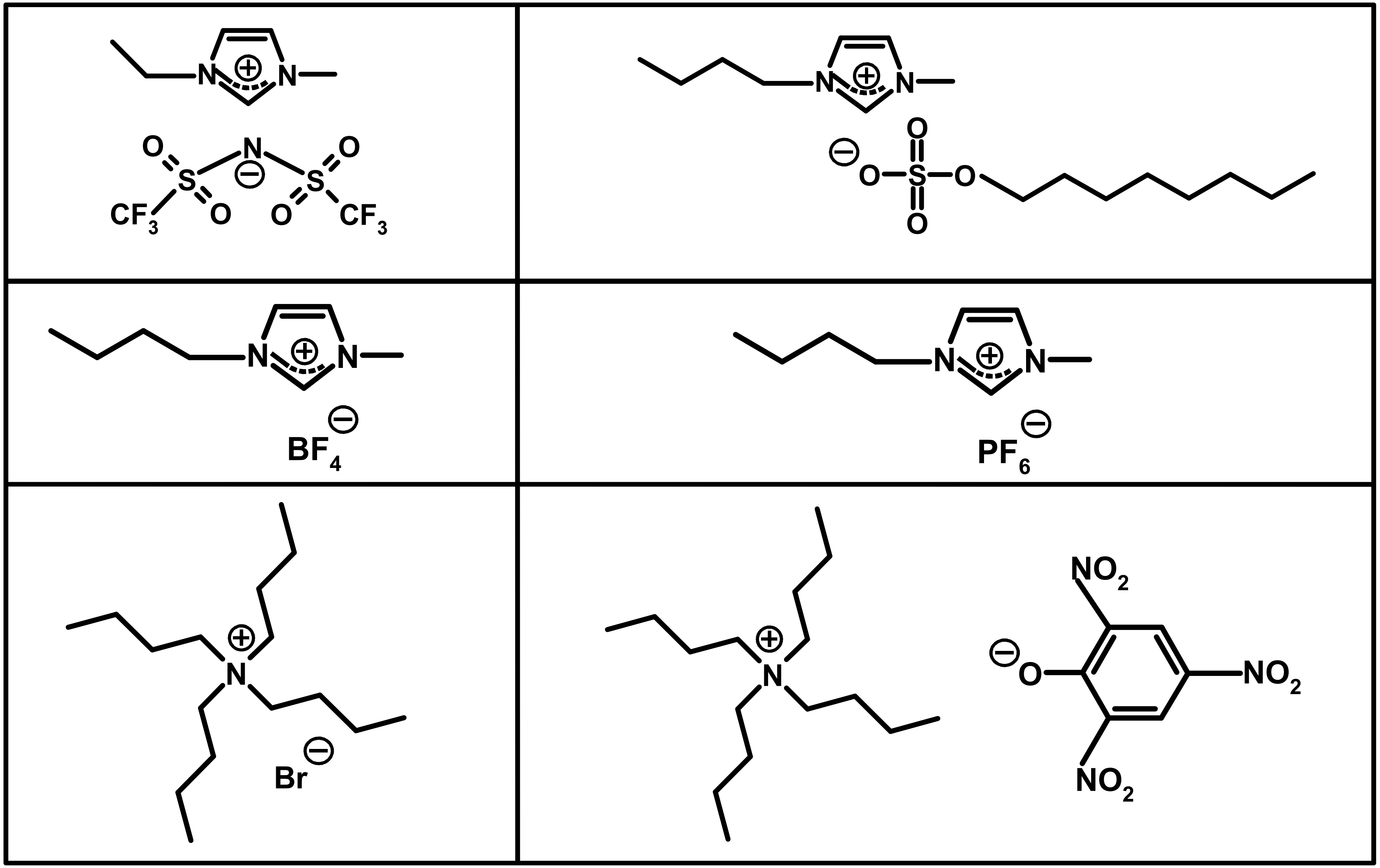
New "Ionic Liquids" as Flame-Retardant Electrolytes

Some Structural Examples with Different Lipophilicity.



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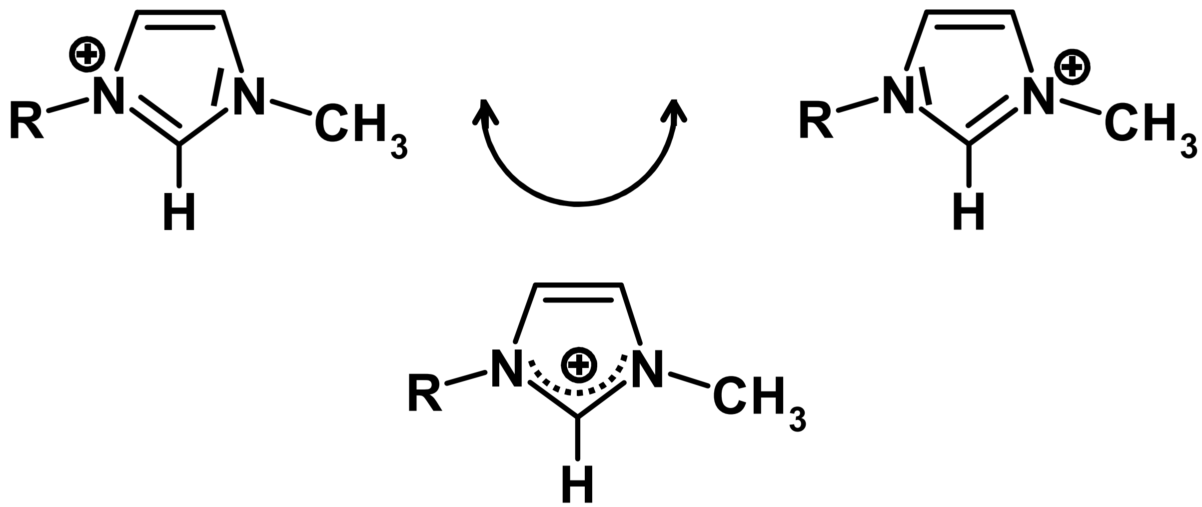
New "Ionic Liquids" as Flame-Retardant Electrolytes

N-Methyl-N-Alkyl-Imidazolium Cation:
Delocalized "3-Center-4-Electron Configuration".



Cationic 3-Center- 4 -Electron System

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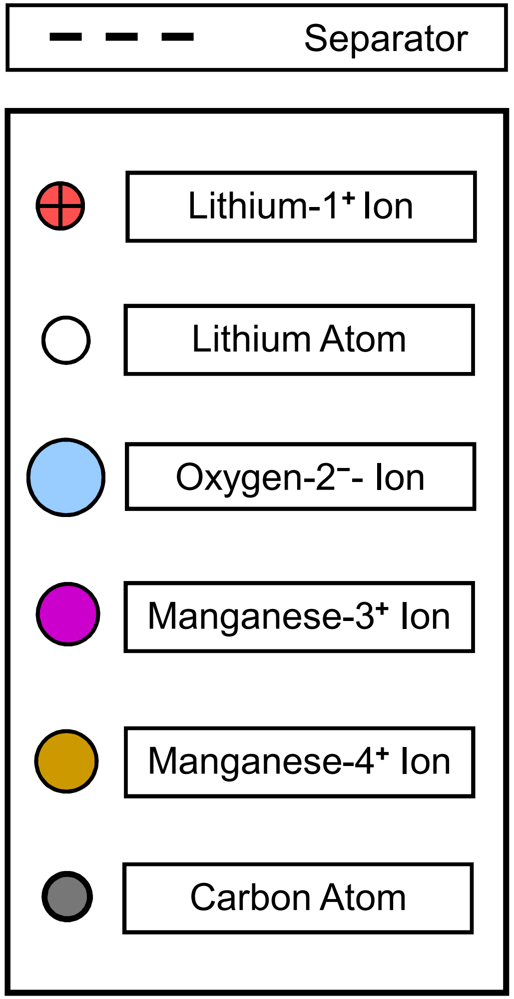
I. L. : Figures on the Material Diversity (Estimates).

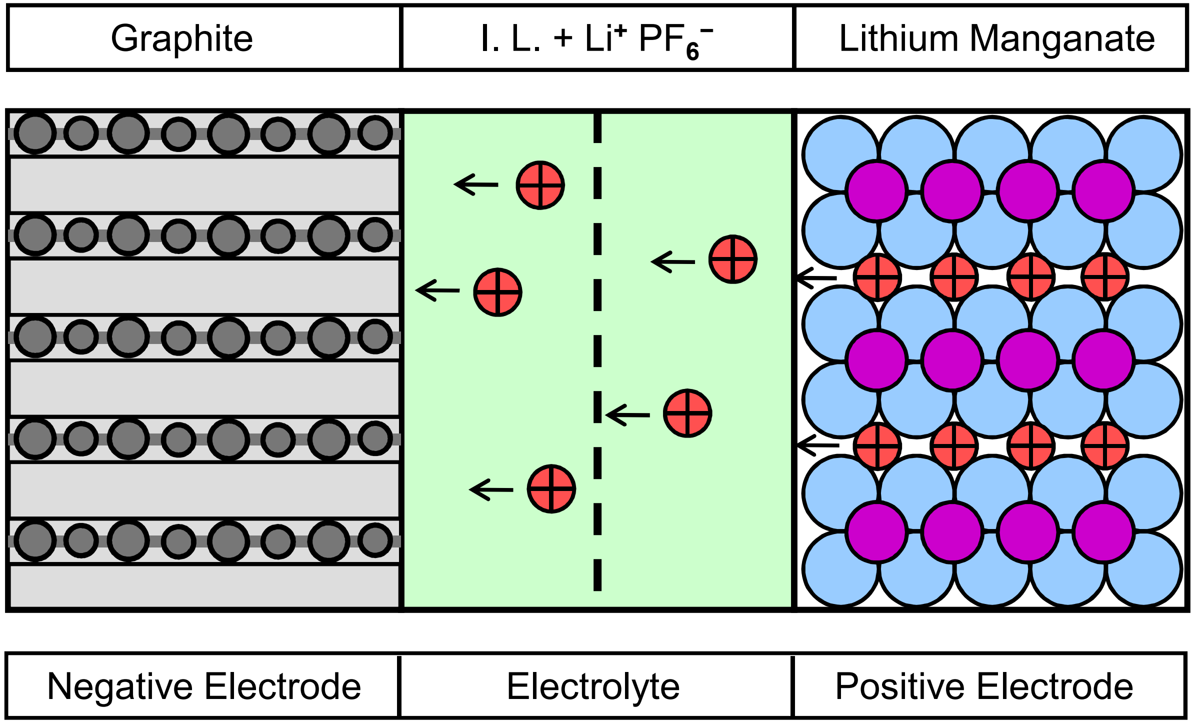
Number of theoretically possible I.L.s (K.R. Seddon)	10^{16}
Number of chemically and synthetically accessible I.L.s	10^{10} - 10^{11}
Number of potentially technically interesting I.L.s	10^{4} - 10^{5}
Number of I.L.s described in the literature up to 2020	>5.000
Number of I.L.s accessible on a laboratory scale in 2020	≈ 800
Number of industrially available I.L.s	≈ 50
Number of I.L.s sufficiently characterized for the commercial use.	≈ 10

The physical and chemical properties of the ionic liquids can be controlled via the structure and charge of the two ions!

New "Ionic Liquids" as Flame-Retardant Electrolytes

Li Ion Cells ($LiMnO_2/C_n$), Start of the Charging Process.





Reaction Equation:

$$Li_{1-x}MnO_2 + Li_xC_n \underset{\textbf{Charging}}{\overset{\text{Discharging}}{\rightleftarrows}} Li\,MnO_2 + C_n$$

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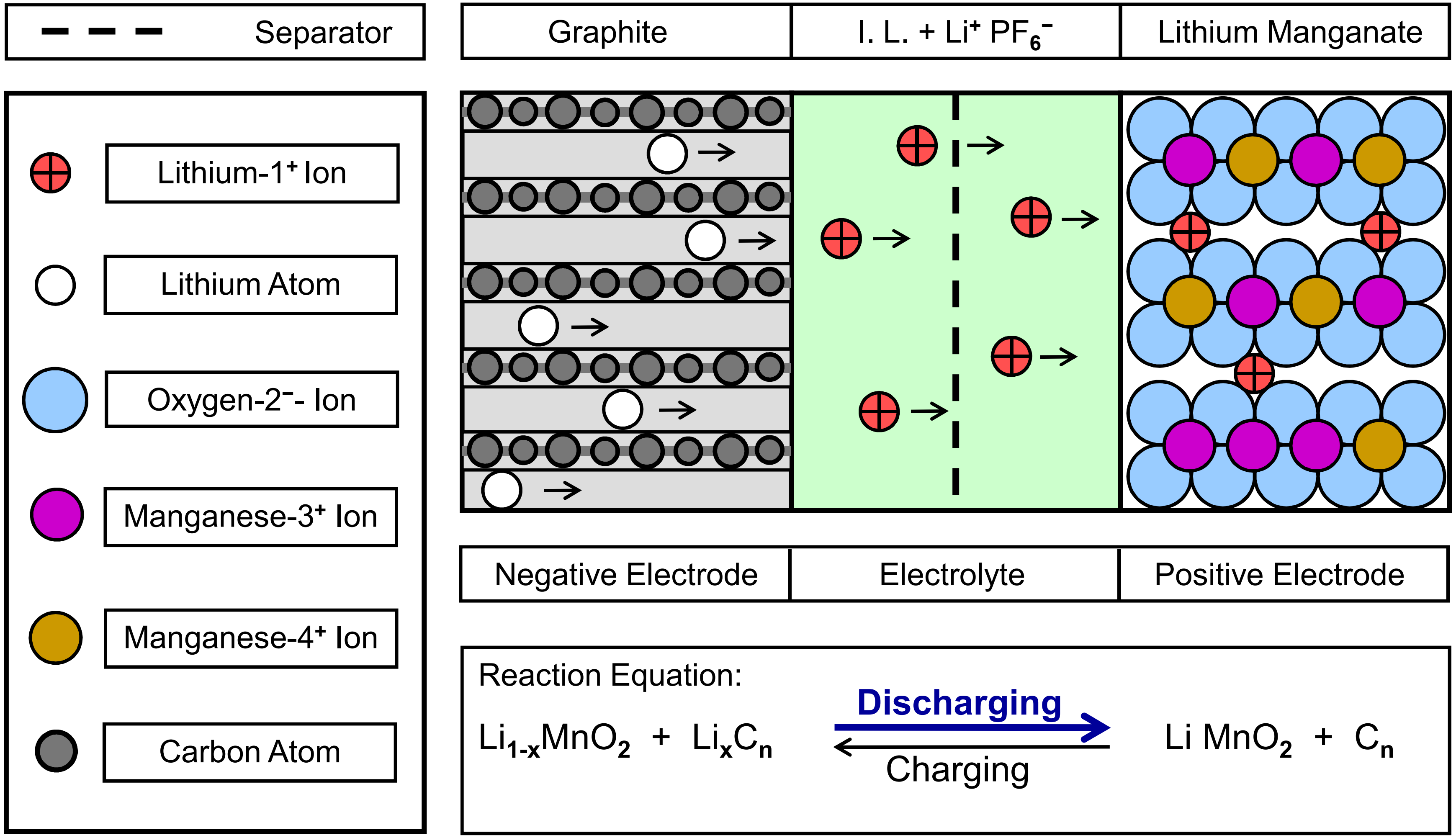
New "Ionic Liquids" as Flame-Retardant Electrolytes

Li Ion Cells ($LiMnO_2/C_n$), Start of the Discharging Process.



Reaction Equation:

$$Li_{1-x}MnO_2 + Li_xC_n \underset{\text{Charging}}{\overset{\text{Discharging}}{\rightleftarrows}} Li\,MnO_2 + C_n$$

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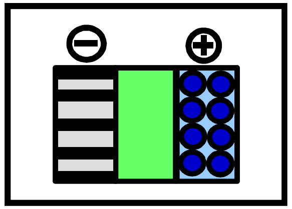
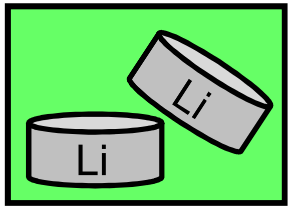
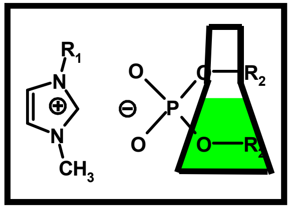
Your innovation target:
New "Ionic Liquids" (I.L.) as flame-retardant electrolyte liquids in lithium-ion cells.



Demand/Need:
Non-flammable and hardly volatile electrolyte liquids in lithium high-performance cells.



Potential chemical solution:
New ionic liquids based on 1-methyl-3-alkyl-imidazolium organophosphates.



The people involved:
Young chemists (m/f/d) in transdisciplinary project teams.

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Case Study Task on R&D Project Management

Task, Part 1

In joint teamwork, plan a plausible R&D project for your envisaged innovation "New Ionic Liquids (I. L.) as flame-resistant electrolytes in lithium-ion cells"!

!

- General Framework: The R&D project to be planned should be of strategic importance for your company "[…GmbH 4]"!
- Define from your sight, what you consider to be a plausible target system for this R&D project: chemical-technical, economic and time objectives, taking into account the state of science, the state of the art, the current development of the market, as well as those of the competition.
  (Use data and facts from the "profile boxes", as well as appropriate information from the "environmental information")!
- Assumption: If all physical, technical and chemical ideal values for your cell-compatible Ionic Liquids are to be reached within 5 years, you need a total of approx. 10.0 FTE of available NE-personnel and around 14.0 FTE of available TE-staff.
- Decide on an appropriate project organization!

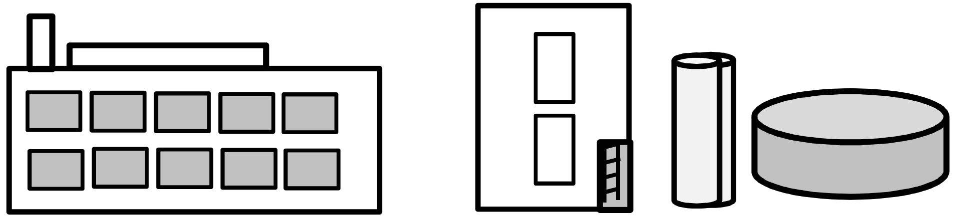
Case Study Task on R&D Project Management

Task, Part 2

In joint teamwork, plan a plausible R&D project for your envisaged innovation "New Ionic Liquids (I. L.) as flame-resistant electrolytes in lithium-ion cells"!

!

■	Determine the target-relevant tasks and classify these according to the number of specialist functions involved in their solution! (The presentation in the form of a table is sufficient!)
■	Based on this, carry out a rough project structure planning (sketch)!
■	Create a first, simple project phase plan by using bars on time axes for this according to the technique of Henry Gantt!
■	Sketch a plausible SWOT analysis for this research project!
■	Make a PowerPoint presentation on the results of your project planning (total duration: Approximately ten minutes)! **"Selected" participants of the respective teams should explain the results of their group work clearly and understandably in around ten minutes!**



Your Chemical Company [...GmbH 4]

Size: "SME", i.e., relatively small specialty chemicals company, a total of 71 employees, including 7 chemists, 9 engineers (FH), 8 engineers (TU), who are currently entrusted with various line tasks and project activities.

Activities: Own research and development, own production.
Active in the field of new "Ionic Liquids" for 6 years with research and development, up-scaling and contract manufacturing. Worldwide sales activities for these products.

Chemical Specialty: Substituted Imidazole-Organica.

Market Need/Demand: Non-flammable, hardly volatile and analytically pure electrolyte liquids for lithium high-performance cells.

New "Ionic Liquids" as Flame-Retardant Electrolytes

Profile Box for Selecting your Target Definitions:

→ **Physical − Technical Data**

Physical-technical requirements for lithium ion cells	**Minimum Requirement** **Ideal Values (Reference)**
Nominal Voltage	3,3 V 4,0 V
Number of charging cycles within 5 years while maintaining 80% storage capacity.	5.000 12.000
Temperature range for an appropriate storage and and for a functioning use.	−35°C to +60°C −45°C to +80°C
Gravimetric Energy Density.	150 Wh/kg 380 Wh/kg
Power Density.	1.000 W/kg 1.600 W/kg
Energy Efficiency.	90% 98%

New "Ionic Liquids" as Flame-Retardant Electrolytes

Profile Box for Selecting your Target Definitions:

→ **Physical − Technical Data**

Chemical-technical requirements for the "Ionic Liquids" as electrolyte liquids in lithium ion cells.	**Minimum Requirement** **Ideal Values (Reference)**
Water Content.	< 100 ppm < 015 ppm
Chloride Content.	< 110 ppm < 050 ppm
Electrical Conductivity.	05 x 10^{-3} S/cm 15 x 10^{-3} S/cm
Viscosity at 25°C.	100 m Pa s 025 m Pa s

New "Ionic Liquids" as Flame-Retardant Electrolytes

Profile Box for Selecting your Target Definitions:

→ Physical − Technical Data

Chemical-technical requirements for the "Ionic Liquids" as electrolyte liquids in lithium ion cells.	**Minimum Requirement** **Ideal Value (Reference)**
Melting Points/ Melting Ranges.	−05 °C −50 °C
Flash points or thermal decomposition temperatures.	> 250°C > 430°C
Possible concentrations of conductive salt.	0,6 mol/l 2,0 mol/l
Miscibility with the usual, aprotic, organic solvents with good wetting of both electrodes and the separator.	8:2-Mixture 1:1-Mixture

New "Ionic Liquids" as Flame-Retardant Electrolytes

Profile Box for Selecting your Target Definitions:

→ **Cost Rates for the Project Staff (FTE).**

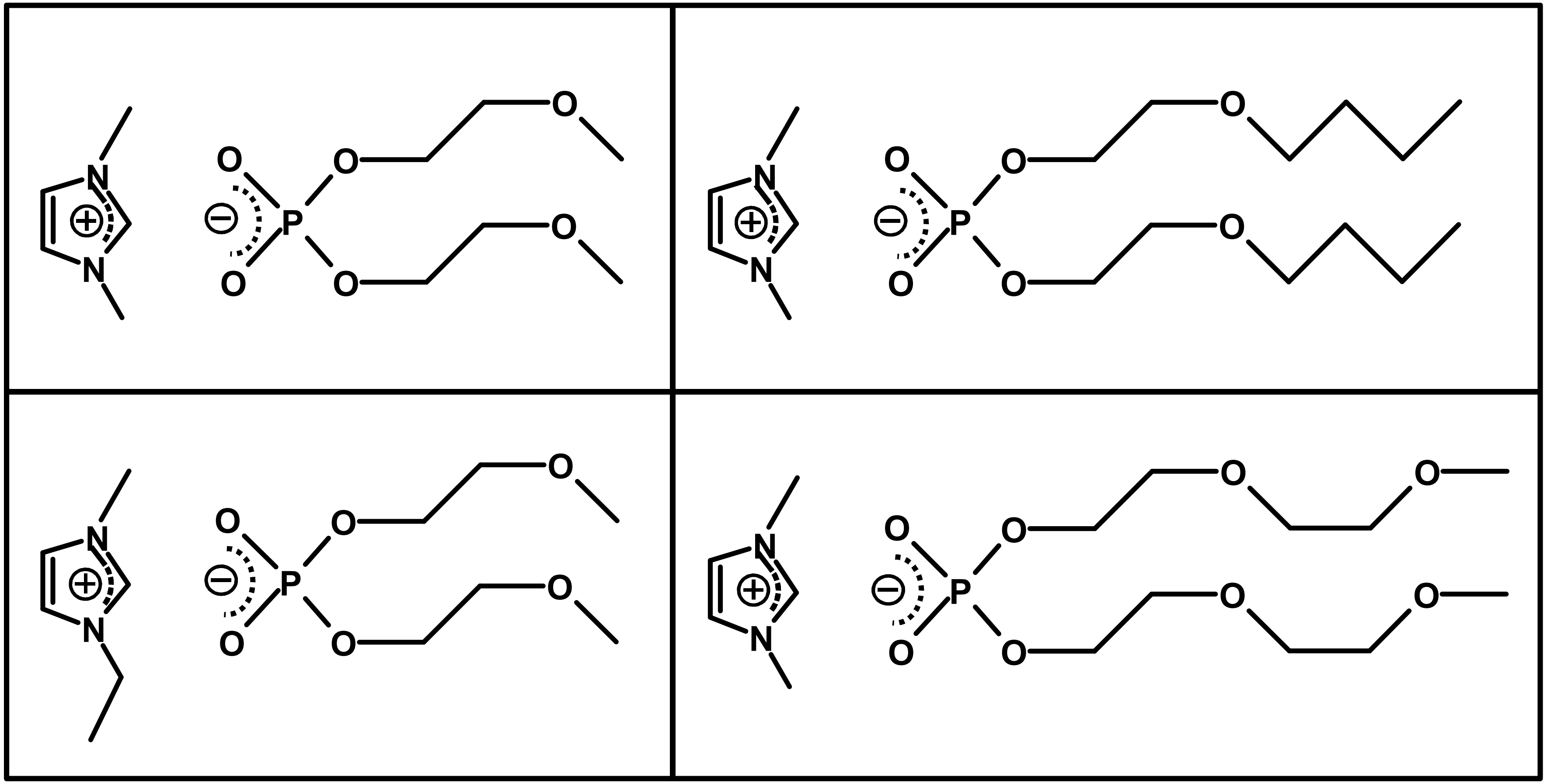
1 FTE	One Full Time Equivalent (One "Employee Year")
Costs	**Non-tariff Employee (NE) : ≈ 240.000€ per Year**
Costs	**Tariff Employee (TE) : ≈ 160.000€ per Year**

NE	Non-Tariff Employees, Managers
	Chemists, engineers, physicists, academically trained business economists, business people, etc., as well as highly qualified and experienced employees (m / f) in the own company
TE	Tariff Employees
	Laboratory workers, office workers, specialists, skilled workers and technicians, each with approx. 40 hours of work a week.

New "Ionic Liquids" as Flame-Retardant Electrolytes

Profile Box for typical chemical **Target Structures.**

Examples of I.L.s that should be miscible with the usual electrolyte liquids for lithium ion cells.



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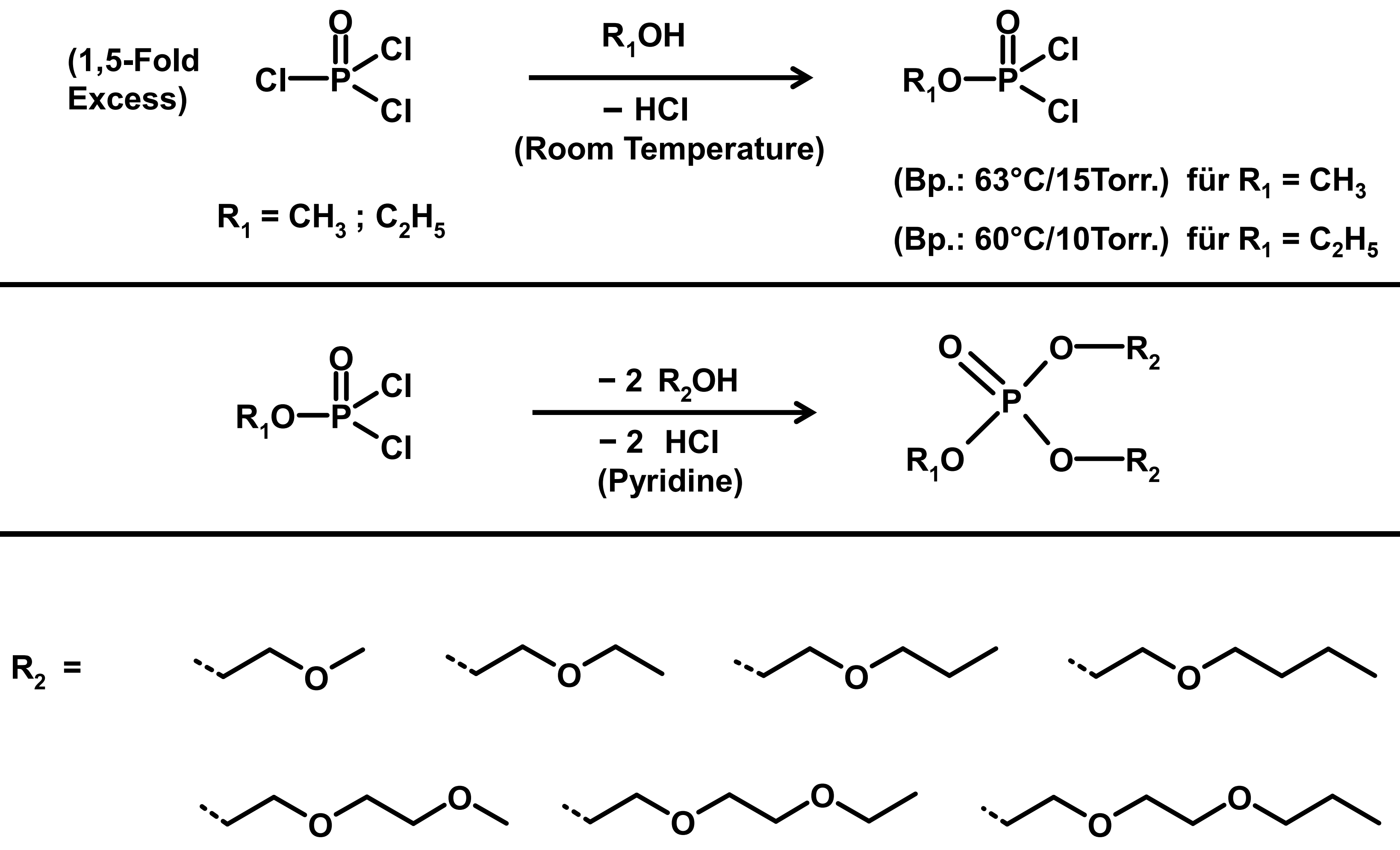
Synthesis of 1-Methyl-3-Alkyl-Imidazolium-O,O-Dialkylenoxy-Phosphates Starting from $POCl_3$ (1).



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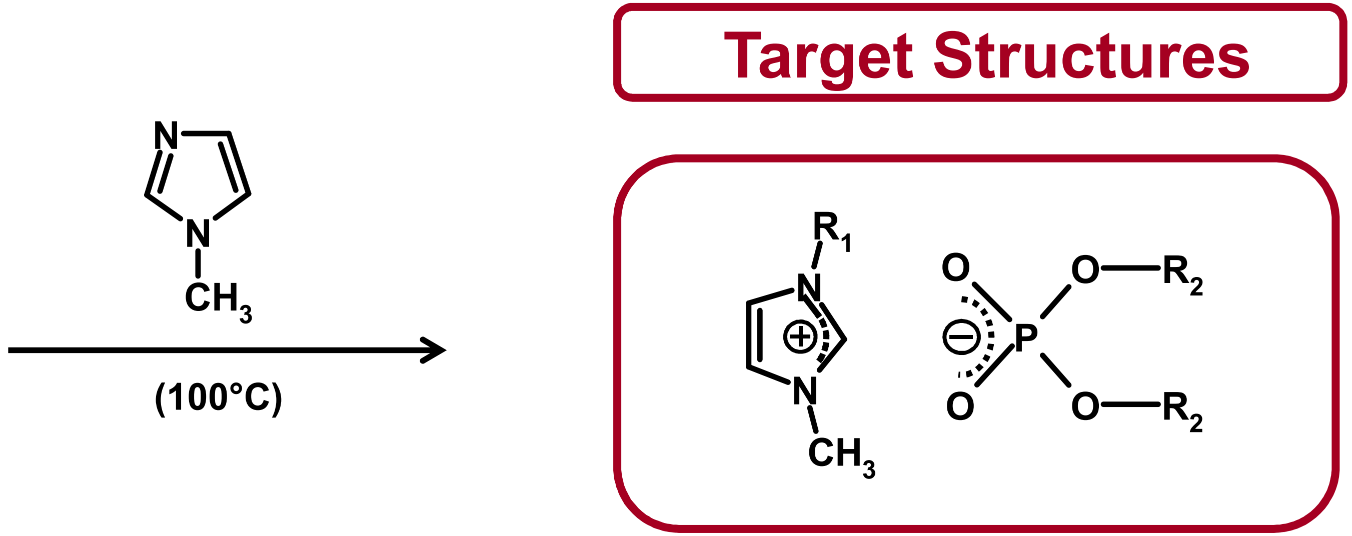
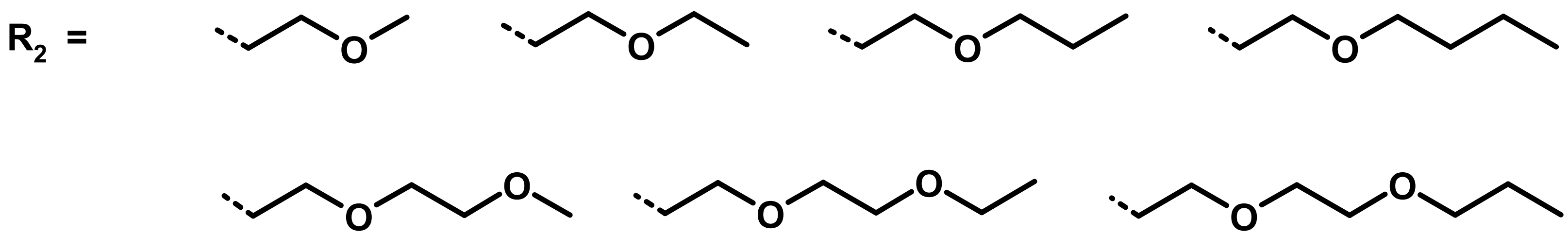
Synthesis of 1-Methyl-3-Alkyl-Imidazolium-O,O-Dialkylenoxy-Phosphates Starting from $POCl_3$ (2).





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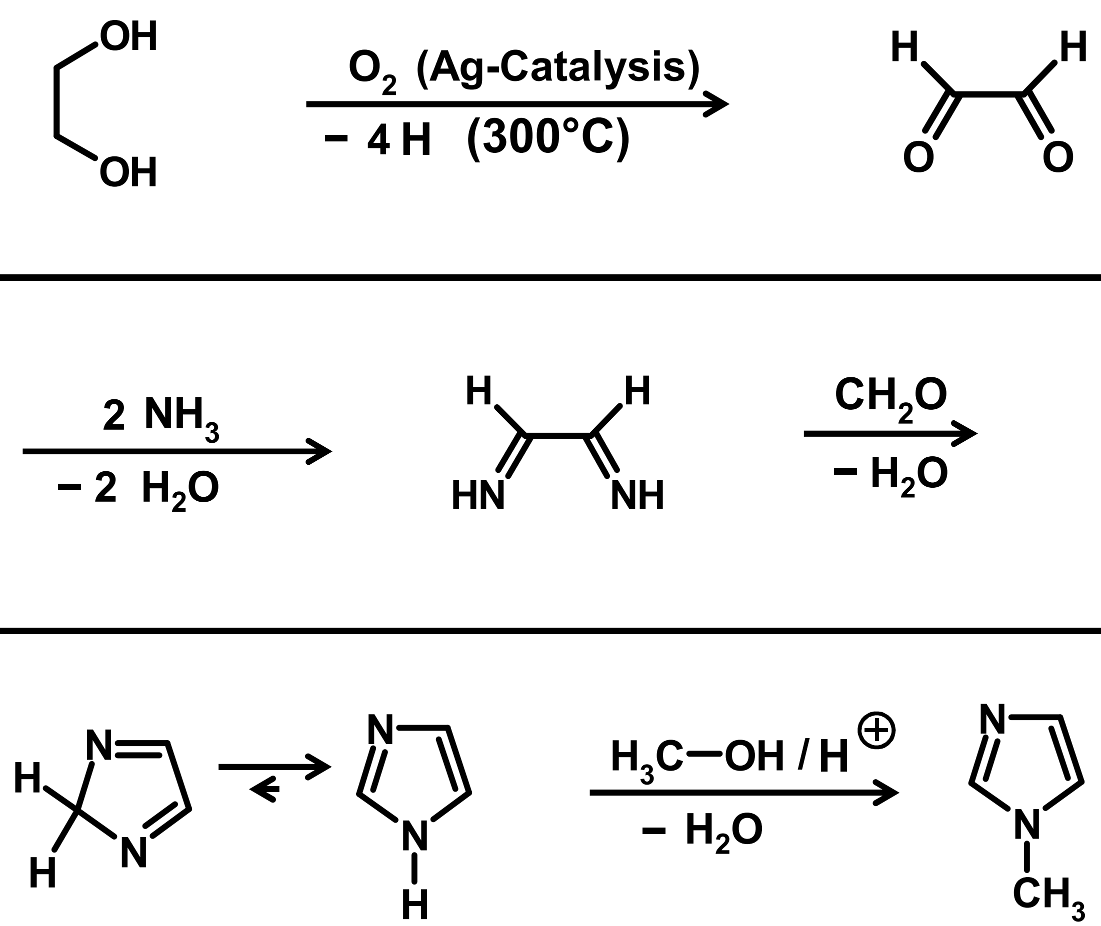
Info-Box: Technical Synthesis of N-Methyl-Imidazole.



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New "Ionic Liquids" as Flame-Retardant Electrolytes

Manufacturing Costs, "M. C.", as well as Development Effort of Other Ionic Liquids, Rough Orientation Values.

Ionic Liquid (I. L.)	Volume	Manufacturing Costs (= M.C.)	≈ Σ in terms of personnel and time
Triethyl-ammonium-hydrogensulfate	1 kg	1 $	-- --
1-Ethyl-3-methylimidazolium methylcarbonate	1 kg	45 €	3 NE, 7 TE, 1,5 Years
1-Ethyl-3-methylimidazolium methanesulfonate	1 kg	135 €	4 NE, 8 TE, 1,5 Years
1-Ethyl-3-methylimidazolium acetate	1 kg	170 €	5 NE, 9 TE, 2,5 Years
1-Ethyl-3-methylimidazolium trifluoromethanesulfonate	1kg	215 € (Electronic Grd.)	8 NE, 14 TE, 3,5 Years
1-Ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide	1 kg	500 € (Electronic Grd.)	12 NE, 18 TE, 5 Years

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New "Ionic Liquids" as Flame-Retardant Electrolytes

Envisaged sales volume of the new ionic liquid suitable for electrical / electronic applications in the period immediately after its market launch: →

Planned Sales Volme: → About **12 t (= 12.000 kg)** per Year.

The following allocations of sales volumes in the market are likely:

Sales Volume, Fields	**Sales volume / requirement for electrolyte per "piece"**
STATIONARY ENERGY STORAGE	**5,0 kg**
ELECTRIC CARS	**1,0 kg**
E-BIKES, PEDELECS	**0,005 kg**

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New "Ionic Liquids" as Flame-Retardant Electrolytes

Project Planning: Environmental Information.

Markets for Lithium Ion Cells (2010/2020)	**Turnover, Billions €**
Mobile Application: **ELEKTRIC CARS** inclusive Plug-in-Hybrides (Traction)	1,2 (2010) **4,0 (2020)**
Mobile Application, Two-Weelers **PEDELECS, E-BIKES, E-SCOOTERs,** etc. (Leisure)	1,1 (2010) **3,4 (2020)**
Mobile Application: Sweeping and cleaning machines, forklifts, etc.	1,4 (2010) 2,8 (2020)
Portable Applications: ("3C-Market"): Communication, Computer, Consumer Electronics	3,2 (2010) 8,5 (2020)
STATIONARY BATTERY STORAGES Storage power plants for renewable energies	0,5 (2010) **1,5 (2020)**
Total, worldwide Turnover. (Growth Rate: 5%/Y) **Sum, Σ (Forecast 2020)**	**7,4 (2010)** **20,2 (2020)**

New "Ionic Liquids" as Flame-Retardant Electrolytes

Project Planning: Further Environmental Information.

Worldwide Stock of Approved ELECTRIC CARS Including all Hybrid Variants, Scenario Until 2030.

Year	Number of Electric Cars Registered Worldwide
2016	1,20 Million
2017	1,95 Million
2018	3,29 Million
2019	≈ 7,9 Million *
2020	≈ 10 Million
2025	≈ 52 Million
2030	≈ 145 Million

* Of which in China ≈ 3.8 Mio.

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Project Planning: Further Environmental Information.

Sales and Turnover Forecast (Worldwide) for E-BIKES:

Year	Worldwide Sales of E-BIKES
2014	31.700.000
2025	40.300.000
2035	≈ 84 Mio. (≈ 11 Mio. E-Scooter)

Year	Worldwide Turnover with E-BIKES
2016	15.700.000.000 $
2025	24.300.000.000 $

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STATIONARY BATTERY STORAGE SYSTEMS.

World market for stationary battery storage **2017**	> 04.000.000.000 $
World market for stationary battery storage **2020**	> 13.000.000.000 $
World market for stationary battery storage **2030**	> 35.000.000.000 $

→ Selling price of a typical stationary battery storage (2017): $ 12,000.

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Project Planning: Further Environmental Information.

- Up to 2025, the energy density of the batteries is expected to increase by 40-50%.

- **Improved electrolytes** and separators with ceramic components will significantly **increase the security** of the energy storage.

- By 2025, 7-10 major cell manufacturers are predicted, including 4-6 global companies and 2-3 Chinese cost leaders.

New "Ionic Liquids" as Flame-Retardant Electrolytes

Project Planning: Further Environmental Information.

Worldwide Demand for Lithium Cells from 2020 to 2030.

Year	Demand in GWh storage capacity (Li-Cells)
2020	≈ 0250
2022	≈ 0450
2024	≈ 0650
2026	≈ 0900
2028	≈ 1150
2030	≈ 1400

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Project Planning: Further Environmental Information.

Worldwide Lithium Cell Production 2018−2028, Σ GWh

Year	"Gigafactories"	Total Capacity GWh
2018	36	= 0226
2023	64	≈ 0980
2028	66	≈ 2020

Largest Lithium Cell Manufacturers (Country)	
LG Chem (South Korea)	CATL (China)
BYD (China)	Panasonic (Japan)
Tesla (U. S. A.)	Samsung (South Korea)

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Project Planning: Further Environmental Information.

Global Price Movements for Lithium Carbonate Li_2CO_3

Year	Price per Ton Li_2CO_3 / Techn. Grade: 99,5%
2015	06.400 $
2016	08.800 $
2017	09.100 $
2018	15.900 $
2019	14.100 $
2020	07.300 $
2025	(Prognosis) ≈ 21.000 $
2030	(Prognosis) ≈ 36.000 $

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Project Planning: Further Environmental Information.

Main Suppliers of Lithium Minerals in 2020:

Country	Numbers converted into pure lithium (t)
Australia	≈ 42.000 t
Chile	≈ 19.000 t
China	≈ 14.000 t
Argentina	≈ 06.400 t
Brasil	≈ 01.900 t
Zimbabwe	≈ 01.400 t
Portugal	≈ 00.900 t
World (total)	≈ 86.000 t

New "Ionic Liquids" as Flame-Retardant Electrolytes

Project Planning: Further Environmental Information.

Accessible Reserves of Lithium Minerals 2020:

Country	Numbers converted into pure lithium (t)
Bolivia	≈ 09.800.000 t
Chile	≈ 09.400.000 t
Australia	≈ 04.800.000 t
Argentina	≈ 01.900.000 t
China	≈ 01.600.000 t
U.S.A.	≈ 00.750.000 t
Canada	≈ 00.520.000 t
Zimbabwe	≈ 00.230.000 t
World (total)	≈ 32.000.000 t

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Project Planning: Further Environmental Information.

Price Development (EURO per Kilowatt Hour) for Electrical Work from Lithium Ion Cells, Worldwide.

Year	Price per kWh
2015	≈ 275 €
2020	≈ 150 €
2025	≈ 075 €
2030	**≈ 050 €**

New "Ionic Liquids" as Flame-Retardant Electrolytes for Li-Ion Cells: **Research groups** and numbers of **patent applications** published annually in this field.

I.L. Researchers

- **Wasserscheid (D)**
- **Kantlehner (D)**
- **Endres (D)**
- **Leitner (D)**
- **Seddon (GB)**
- **Welton (GB)**
- **Rogers (U.S.A.)**
- **Davies (U.S.A.)**
- **Maginn (U.S.A)**
- **Mc Farlane (AUS)**
- **Watanabe (J)**
- **Ohno (J)**
- **Dong (TJ), …et al.**

Patent Applications for Li Ion Cells, Worldwide

Year	Number
2010	143
2011	224
2012	316
2013	404
2014	481
2015	487
2016	482
2017	476
2018	540
2019	616
2020	768

Cell Researchers

- **Besenhard (†) (A)**
- **Goodenough (U.S.A.)**
- **Wittingham (U.S.A.)**
- **Winter (D)**
- **Wang (U.S.A.)**
- **Cheng (U.S.A.)**
- **Ellis (CDN)**
- **Dahn (CDN)**
- **Yoshino (J)**
- **Mizuno (J)**
- **Kobayashi (J)**
- **Kazunori (J)**
- **Jeon (ROK), …et al.**

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End of Supplementary Module 01

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