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Course of development of the lithium-ion battery (LIB), and recent technological trends

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Classification of batteries and the positioning of the lithium ion battery

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	Aqueous electrolyte battery	Nonaqueous electrolyte battery
Primary battery	Manganese dry cell Alkaline dry cell	Metallic lithium battery
Secondary battery	Lead-acid battery, Ni-Cd battery, Ni-MH battery	**Lithium ion battery (LIB)**

What is the lithium ion battery (LIB) ?

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The LIB is a non-aqueous secondary battery using

carbonaceous material as the negative electrode and

transition metal oxides containing Li-ion (ex. $LiCoO_2$) as the positive electrode.

Brief history of LIB development

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1981	Start of basic research on polyacetylene (PA)
82	Application of PA as a negative material
83	**New battery system "PA/$LiCoO_2$"**
84	
85	**New battery system "carbon/$LiCoO_2$"**
86	
87	
88	
89	
1990	
91	
92	Commercialization of the LIB

Identifying problems and finding solutions

Development of manufacturing process

Research

Development

Application

The start of basic research on the LIB was with polyacetylene (PA)

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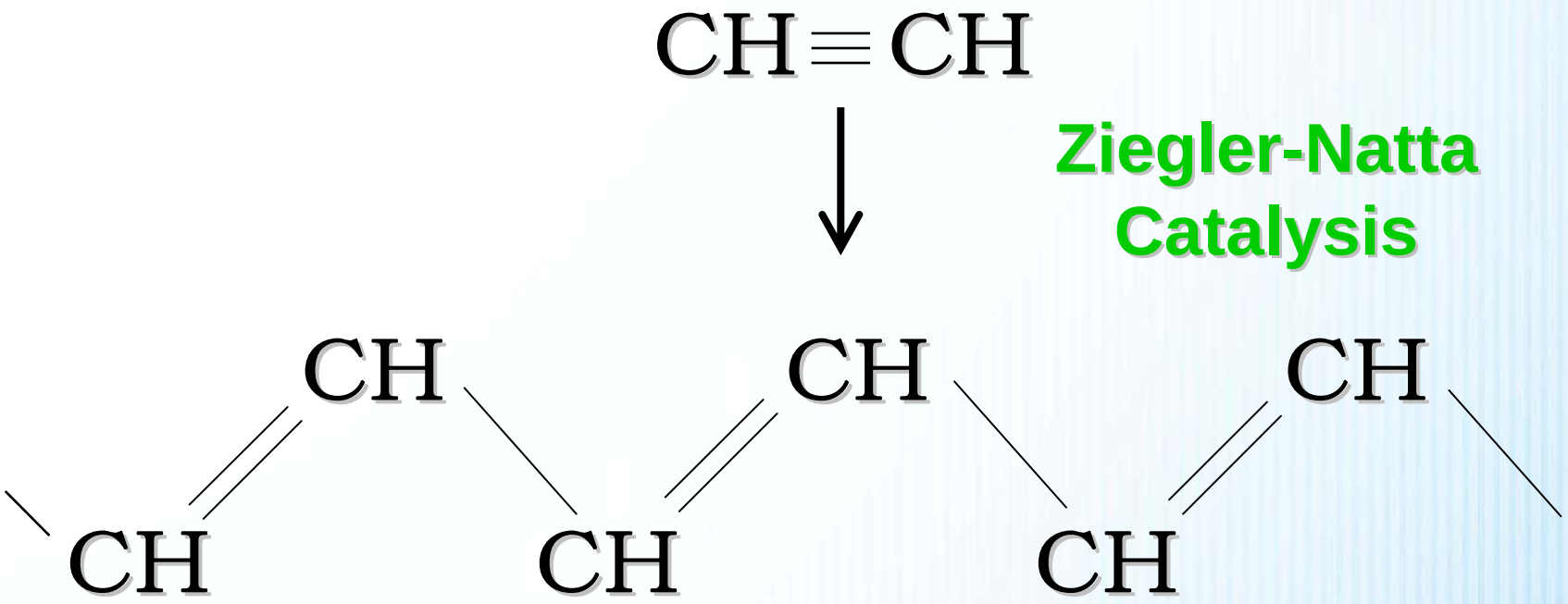

Discovered by A.G. MacDiarmid
A.J. Heeger
H. Shirakawa

The reason why I tried to apply PA as a negative material

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	Aqueous electrolyte battery	Nonaqueous electrolyte battery
Primary battery	Manganese dry cell Alkaline dry cell	Metallic lithium battery
Secondary battery	Lead-acid battery, Ni-Cd battery, Ni-MH battery	**Fatal issues with metallic lithium as negative electrode**

Selection of positive material to be combined with PA was a major issue

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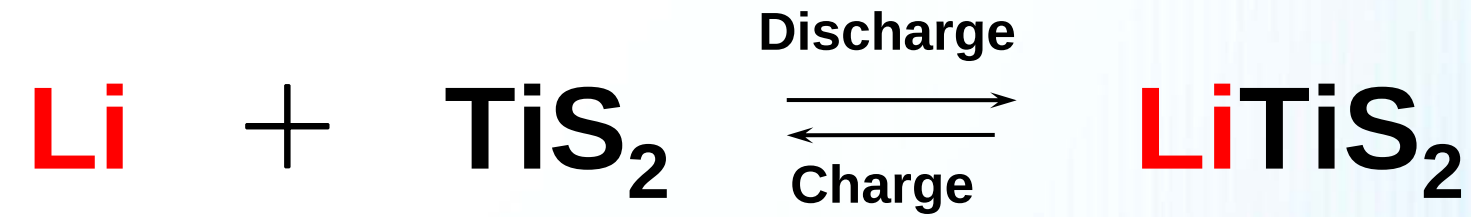
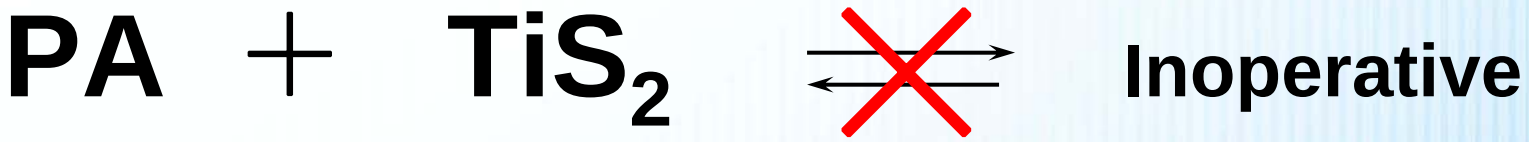
Metallic Li battery:





Not possible to make a battery by substituting PA for Li as negative material

Encounter with the first positive material containing Li ion

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In 1980, J.B. Goodenough et al. reported the first research on $LiCoO_2$ as a positive material for secondary battery

J.B. Goodenough et al.,
***Material Research Bulletin*, 15 (1980) 783**

The origin of present LIB

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$$PA + LiCoO_2 \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} PA^- Li^+ + Li_{1-x}CoO_2$$

The origin of the present LIB

was the PA / $LiCoO_2$ system

I invented in 1983

JP 85-127669 (Application date: Dec. 13, 1983)

Completion of the present LIB principle

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$$C + LiCoO_2 \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} C^- Li^+ + Li_{1-x}CoO_2$$

This new battery system C / $LiCoO_2$ was invented in 1985

JP 1,989,293 USP 4,668,595 EP 205,856B2

(Application date: May 10, 1985)

Safety

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	Aqueous electrolyte battery	Nonaqueous electrolyte battery
Primary battery	Manganese dry cell Alkaline dry cell	Metallic lithium battery
Secondary battery	Lead-acid battery, Ni-Cd battery, Ni-MH battery	**The fatal issue was SAFETY**

The world's first safety test of the LIB

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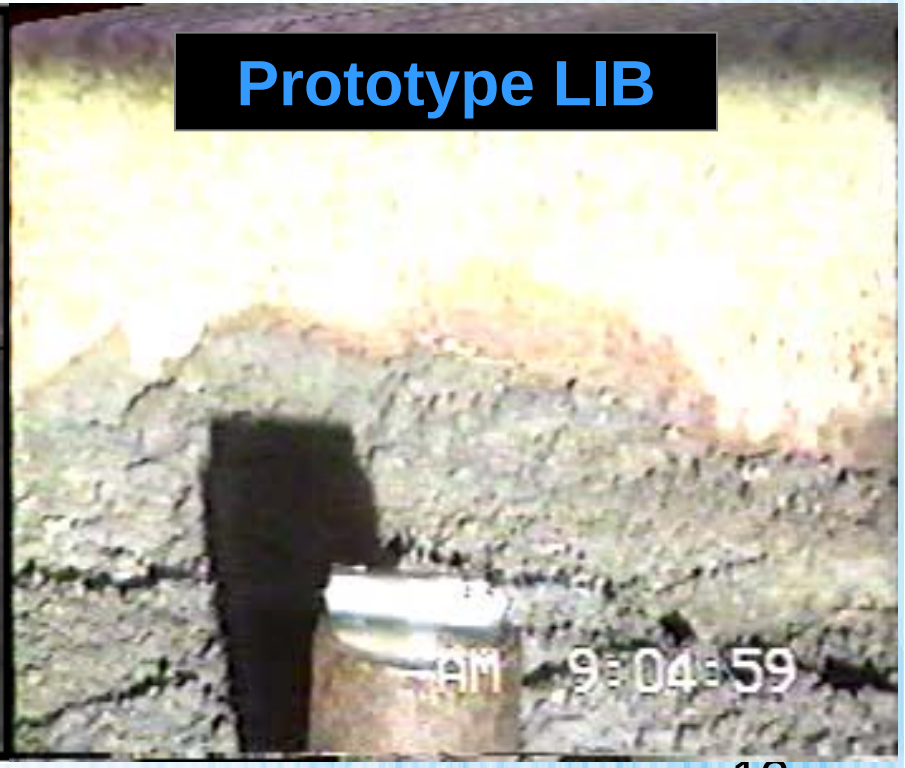
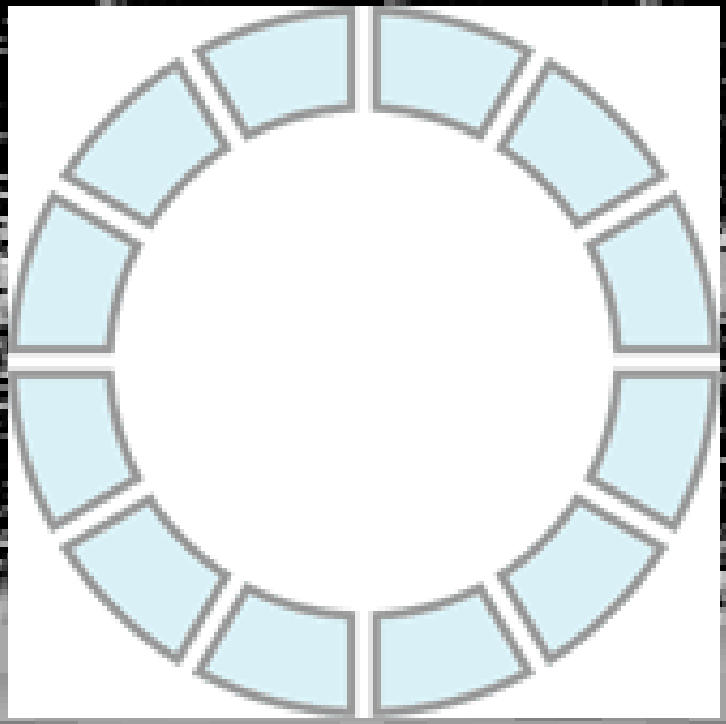
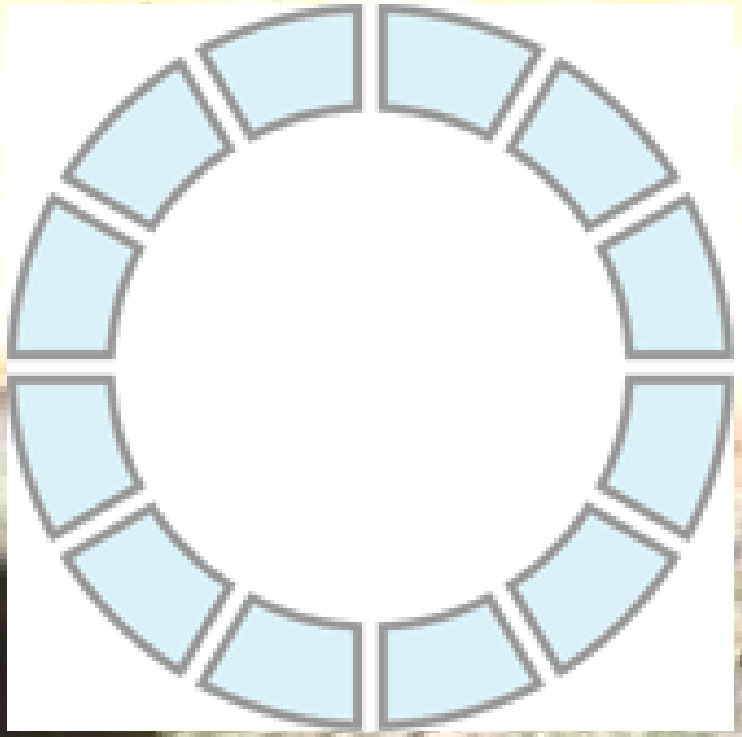
In the summer of 1986,
at Asahi Kasei's explosives plant
in Nobeoka, Japan



Metallic Li primary battery



Prototype LIB



Features of the lithium ion battery

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General features

1. Small and lightweight
2. High electromotive force
3. High current discharge
4. No harmful substances contained (ex. Cd, Pb)

Features for energy storage applications

1. High charge/discharge efficiency

   Current efficiency: 100% Electric power efficiency: 95%

2. Low self-discharge rate: 7–8% per month

Energy and price of current lithium ion battery

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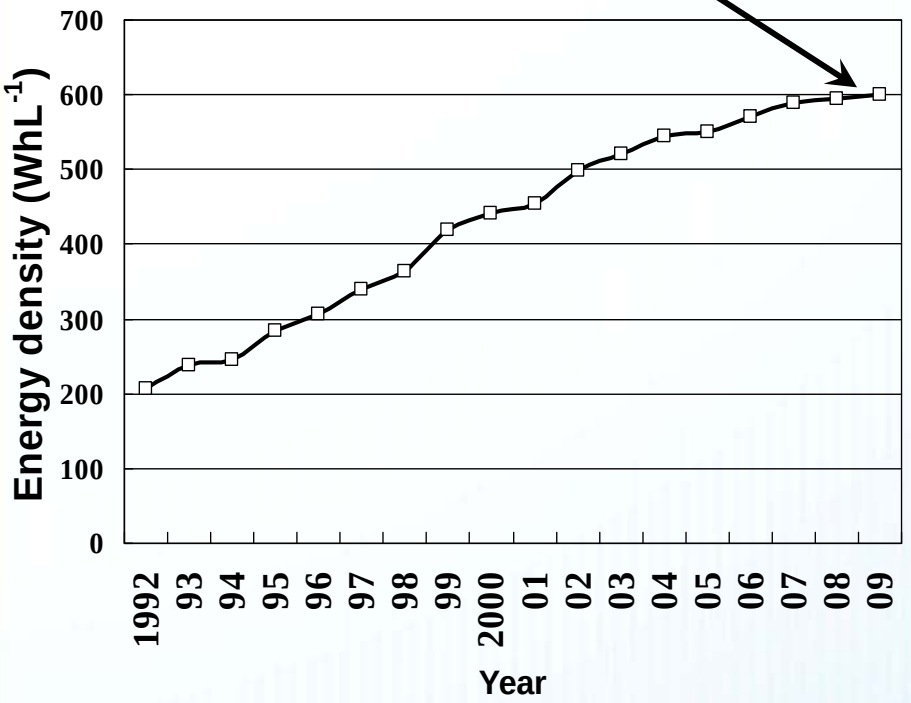
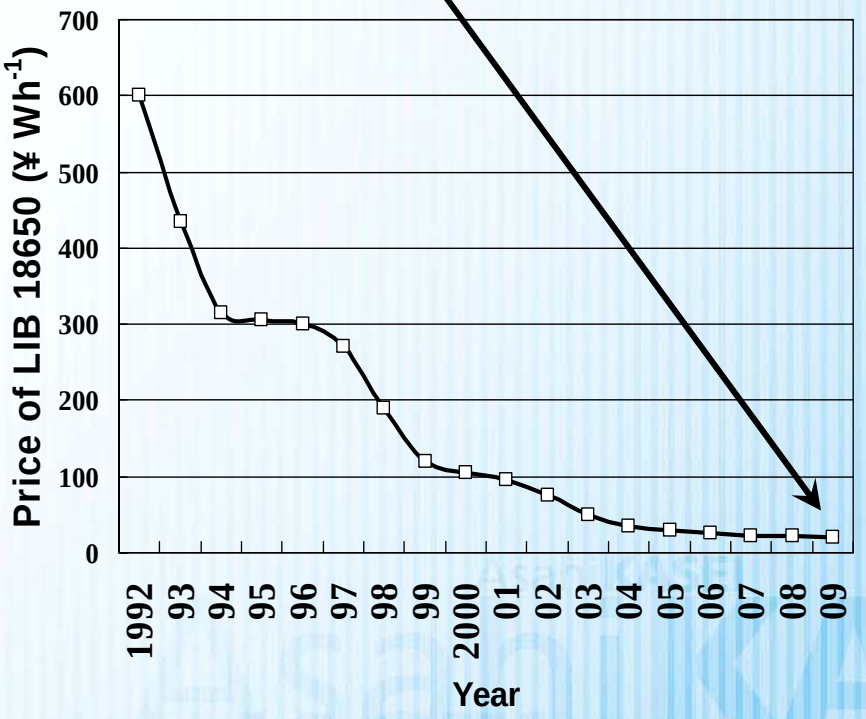
Bare cell energy of cylindrical 18650

Energy density: 600 Wh L^{-1}
Specific energy: 222 Wh Kg^{-1}



Bare cell price of cylindrical 18650

¥200 / (2.4Ah × 3.7 V) = ¥22.5 Wh^{-1}



Notable future market trends

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1. Consumer use (IT)

Growth of cellar phone and notebook computer market and new applications such as power tools

2. Automobiles

HEV (Hybrid Electric Vehicle)

PHEV (Plug-in Hybrid Electric Vehicle)

BEV (Battery Electric Vehicle)

3. Energy storage

Electricity storage system for solar cell and wind power