Seminar: Activities for Lead-cooled Fast Reactors (LFR) in Generation IV International Forum (GIF)
Tamachi Campus, Tokyo Institute of Technology,
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Data Related to LFR

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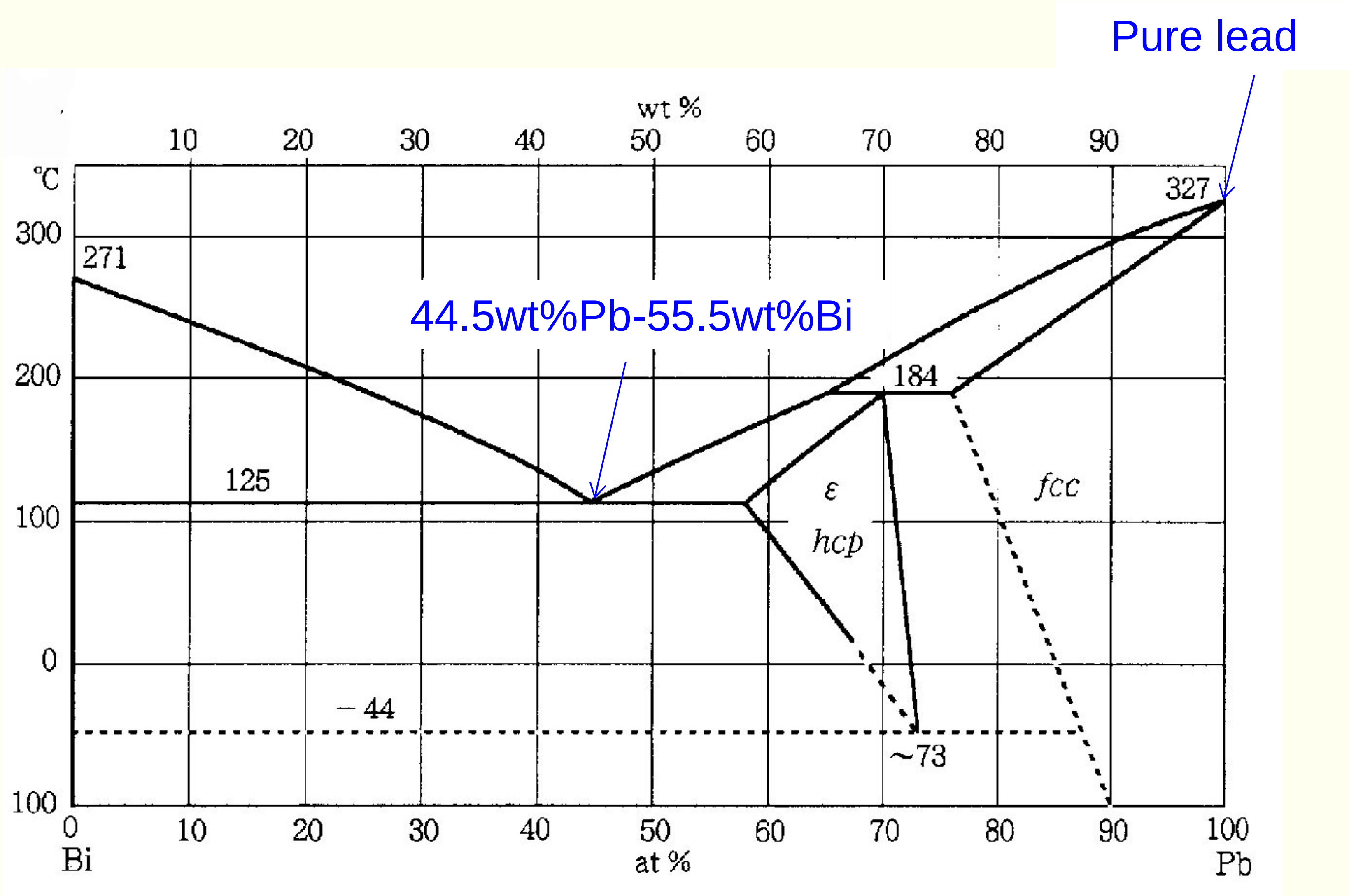
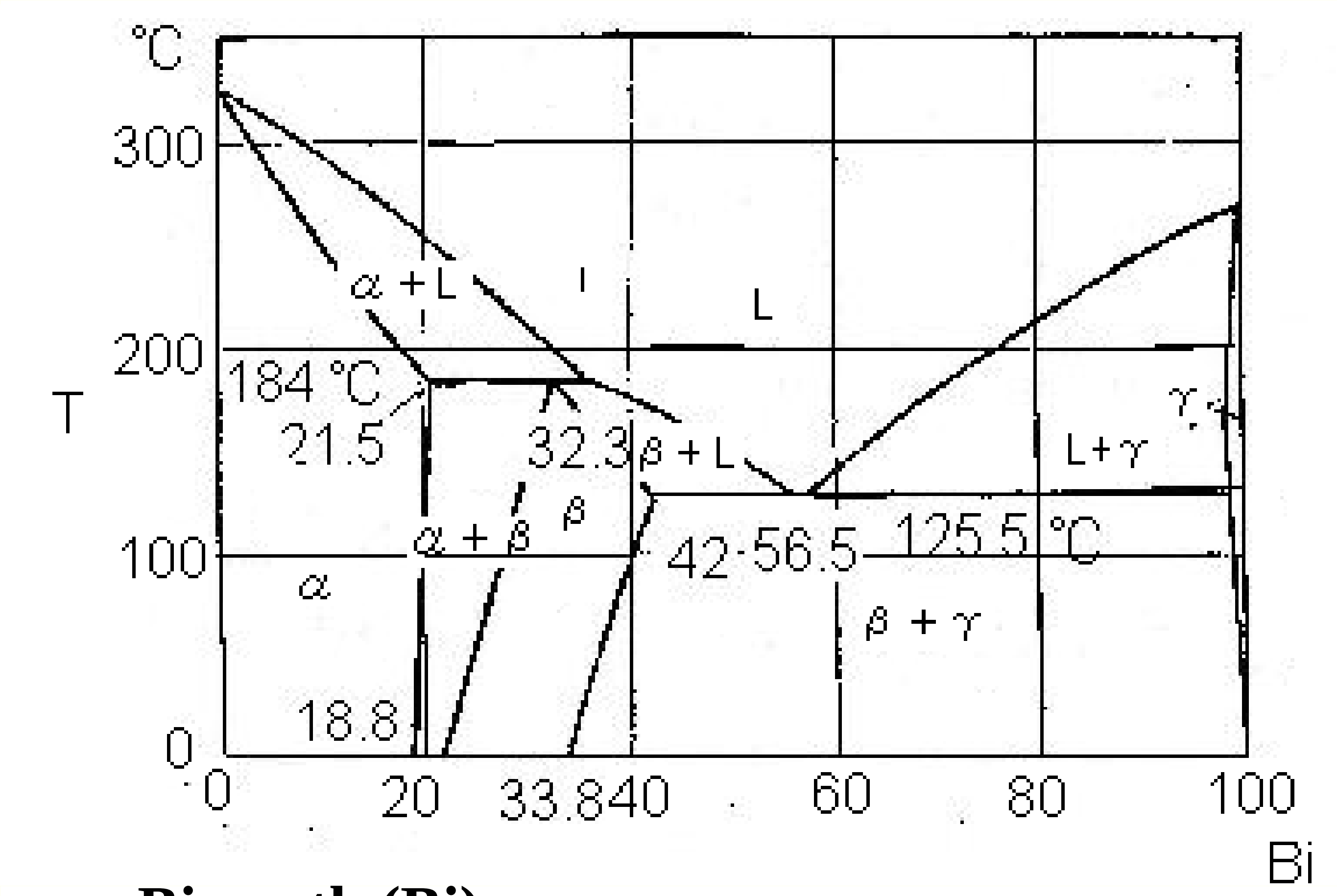
Phase Diagram of Lead-bismuth Alloy



Ref. Nigen Gokin Jotaizu Shu, AGNE Gijutsu Center, 2001 (in Japanese)

Phase Diagram of Lead-bismuth Alloy



Bismuth (Bi)

- Ore with Bi contents of 5 - 25% is rare
- Abundant in Bolivia, Tasmania, Peru, Spain
- Proven reserved in the world: 260,000t

Issue of Polonium (Po)

Production of Po-210 from Bi-209

$Bi^{209} + n \rightarrow Bi^{210} \rightarrow Po^{210} \rightarrow Pb^{206}$

Bi^{210} : β^{-}decay, $T_{1/2}$=5day

Po^{210} : α-decay (5.3MeV), $T_{1/2}$=138.4day

Contamination, leak and exposure of Po-210:

If Po-210 leaks contaminate floors and air as aerosol, gaseous Po, Po hydrate, internal exposure is possible in maintenance.

Po-210 measure:

1. Confinement of Po-210 by means of quick solidification of Pb-Bi and application of lacquer on the surface of the solid Pb-Bi.
2. Removal of Po-10 by means of baking and filtering

Nitride Fuel (PuN, UN)

Properties suitable for LFR design

- High Density
- High thermal conductivity
- High Melting Point 2780˚C

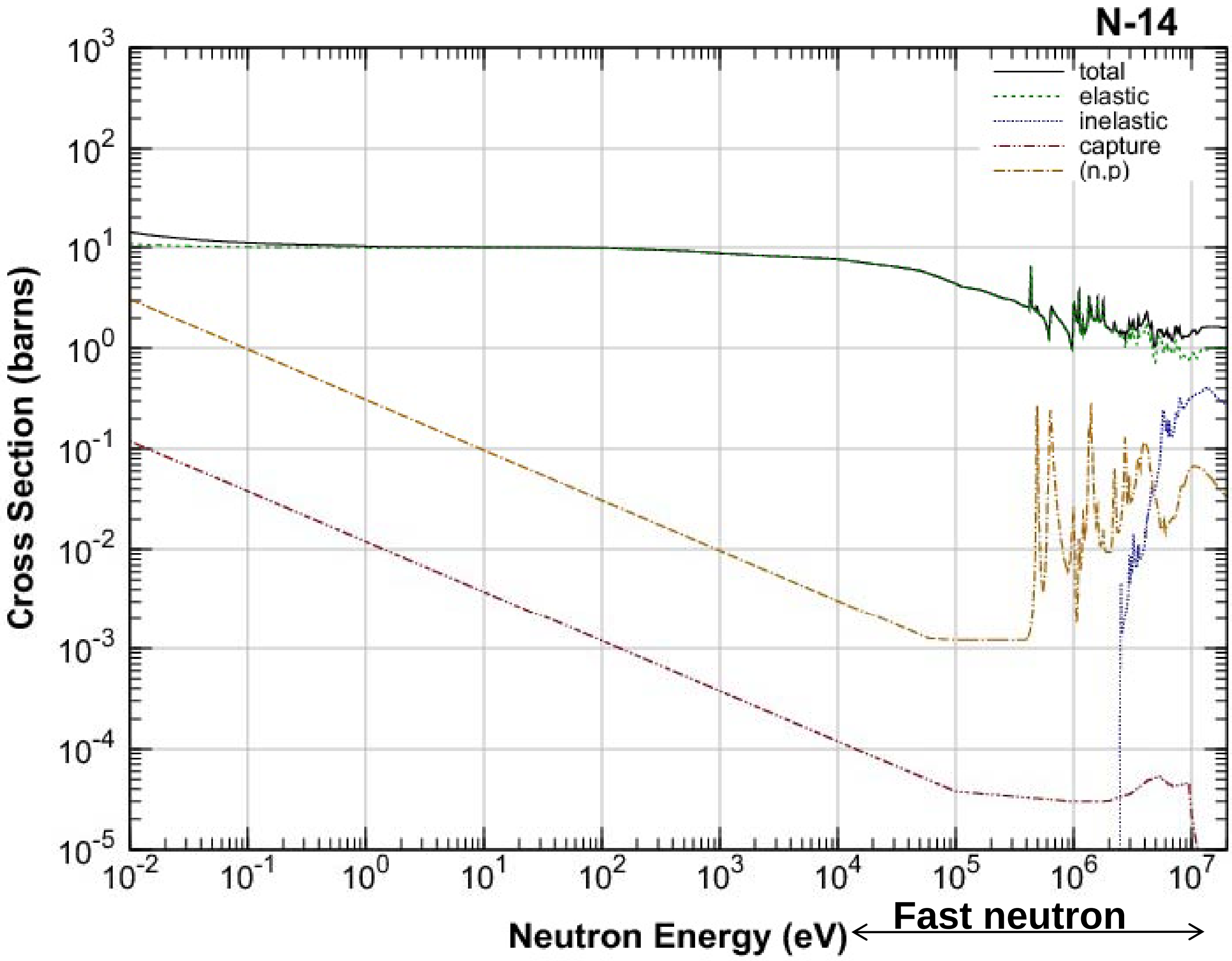
Isotopes	Abundance in nature (%)
N-14	99.63
Na-15	0.37

Issues

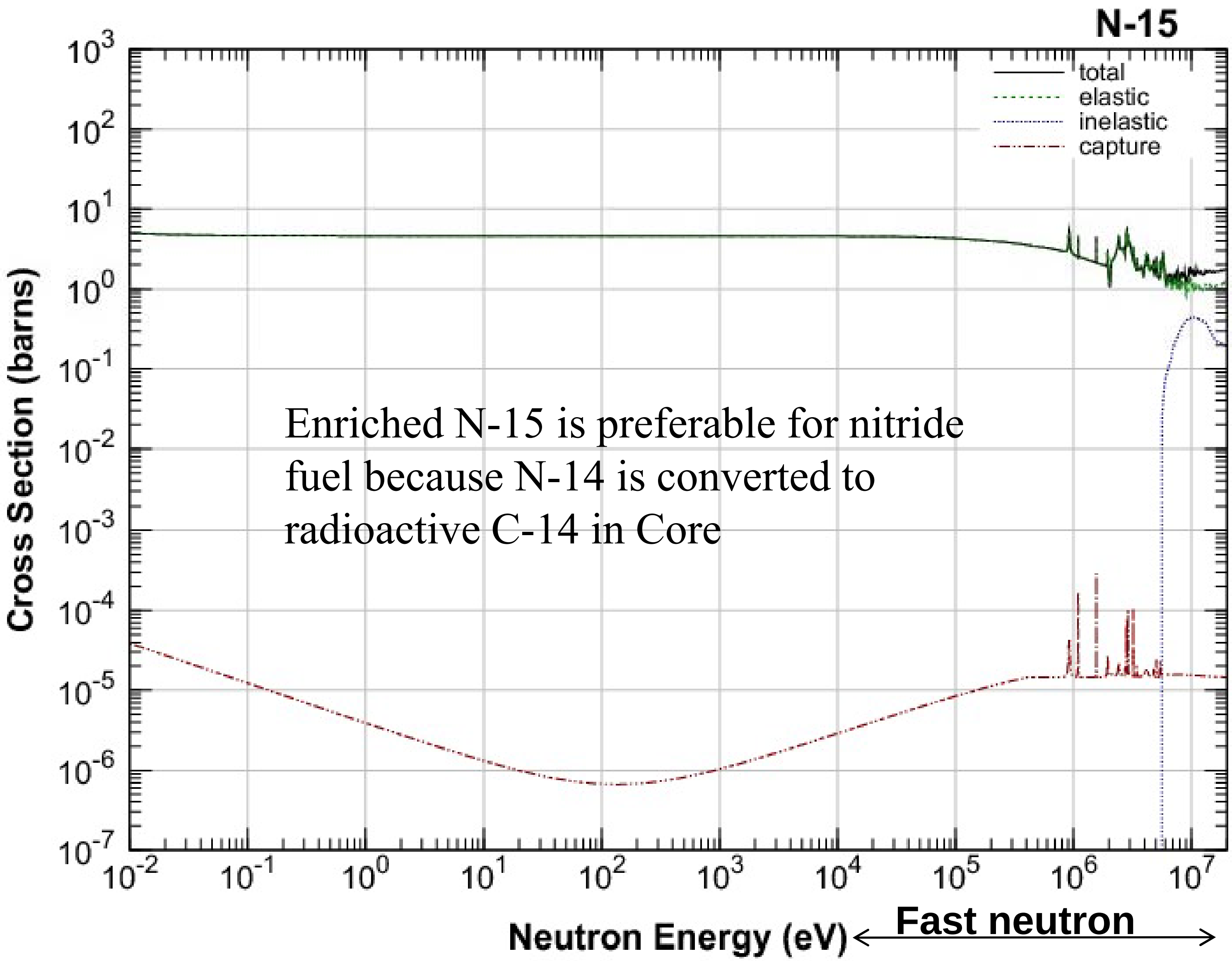
- N-14 → C-14 (Radioactive)
- High enrichment of N-15 required
- Recycling of N-15 required
  → Pyrochemical reprocessing (Dry reprocess with molten salt) is suitable for recycling

Problem

- Decomposition of PuN, UN occurs above certain temperature



N-14
total
elastic
inelastic
capture
(n,p)
Cross Section (barns)
Neutron Energy (eV)
Fast neutron


N-15
total
elastic
inelastic
capture
Cross Section (barns)
Neutron Energy (eV)
Fast neutron
Enriched N-15 is preferable for nitride fuel because N-14 is converted to radioactive C-14 in Core

Abundance of Pb and Na isotopes

Isotopes	Abundance in nature (%)	Half life (y)	Decay type	Product of decay	Cross section (b)	
					Scattering (10^{-2}eV-1MeV)	(n,2n) （10-15MeV）
Pb-204	1.4	1.4×10^{17}	α	Hg-200	~10	~2
Pb-206	24.1	Stable	-		~10	~2
Pb-207	22.1	Stable	-		~10	~2
Pb-208	52.4	Stable	-		~10	~2
Pb-210	-	22.3	α, β	Hg-206, Bi-210	-	-

Isotopes	Abundance in nature (%)
Bi-209	100

Isotopes	Abundance in nature (%)	Half life
Na-22		2.6 y
Na-23	100	
Na-24		15.0 h
Na-25		60 s

-Pb-208 has high performance due to its low capture cross section (see GLABAL 2011 Paper No.398761)

-Pb-208 is the final stable nucleus in Th decay chain

-Pb-206 is low activation coolant (see ICONE-8385)

Nuclear Data of Pb, Pb-Bi and Na

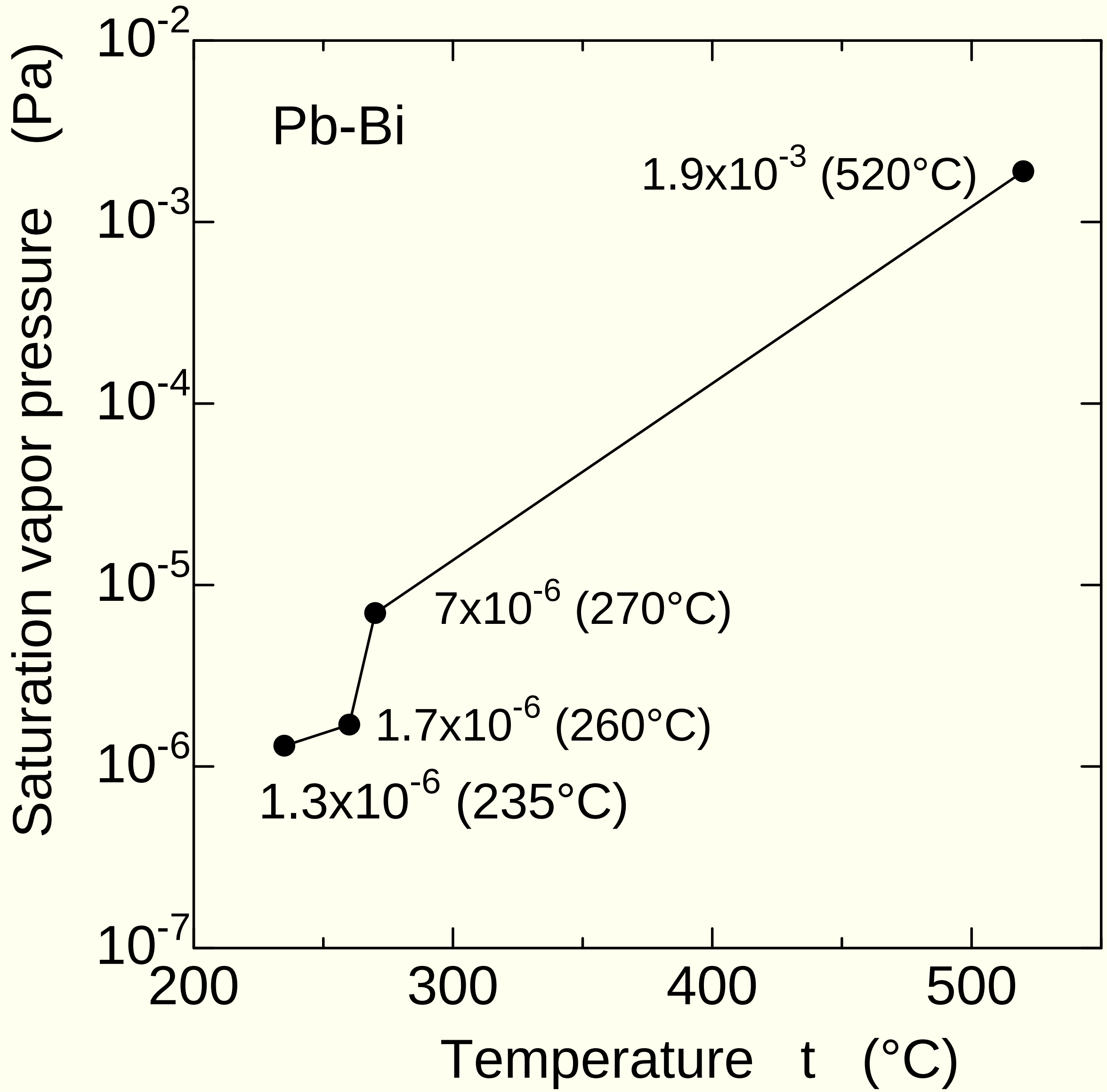
(700K, Neutron energy of 0.5 MeV)

	45%Pb-55%Bi	Pb-207	Pb-208	Na
Scattering cross section (b)	7.5	8	7	4
Capture cross section (b)	$2x10^{-3}$	$4x10^{-3}$	$1x10^{-3}$	$8x10^{-4}$
Mean free path in scattering (cm)	4.5	4.1	4.7	11.2
Slowing-down power (cm^{-1})	0.0021	0.0023	0.0020	0.0075
Moderating ratio (-)	36	19	67	422

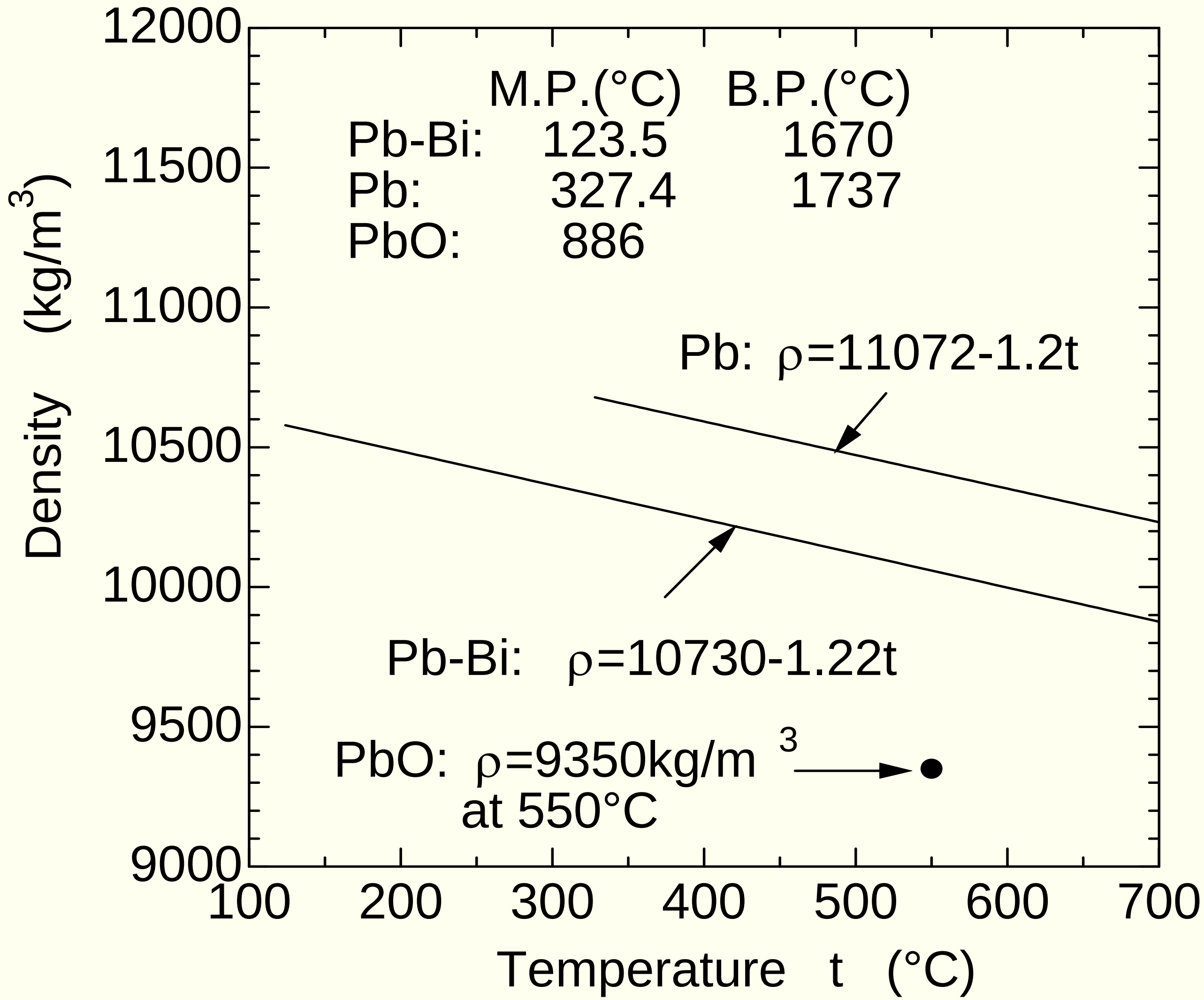
Properties of Pb, Pb-Bi and Na

	Pb	45%Pb-55%Bi	Na
Density ((kgm^{-3}) at 427 ˚C	10,480	10,210	849
Melting point (˚C)	327	124	98
Boiling point (˚C)	1,737	1,670	880

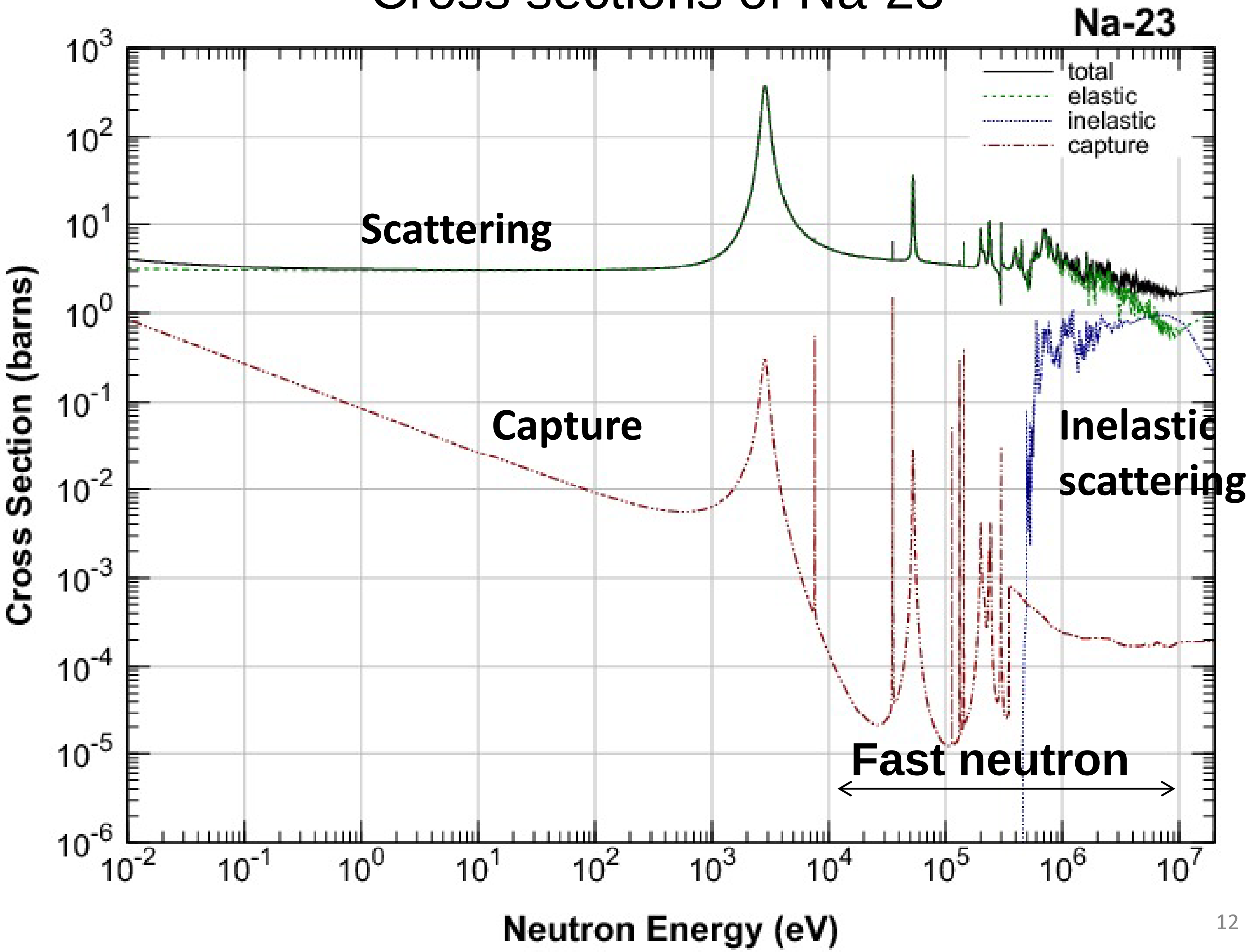
Vapor Pressure of Pb-Bi



Density of Pb, Pb-Bi and PbO

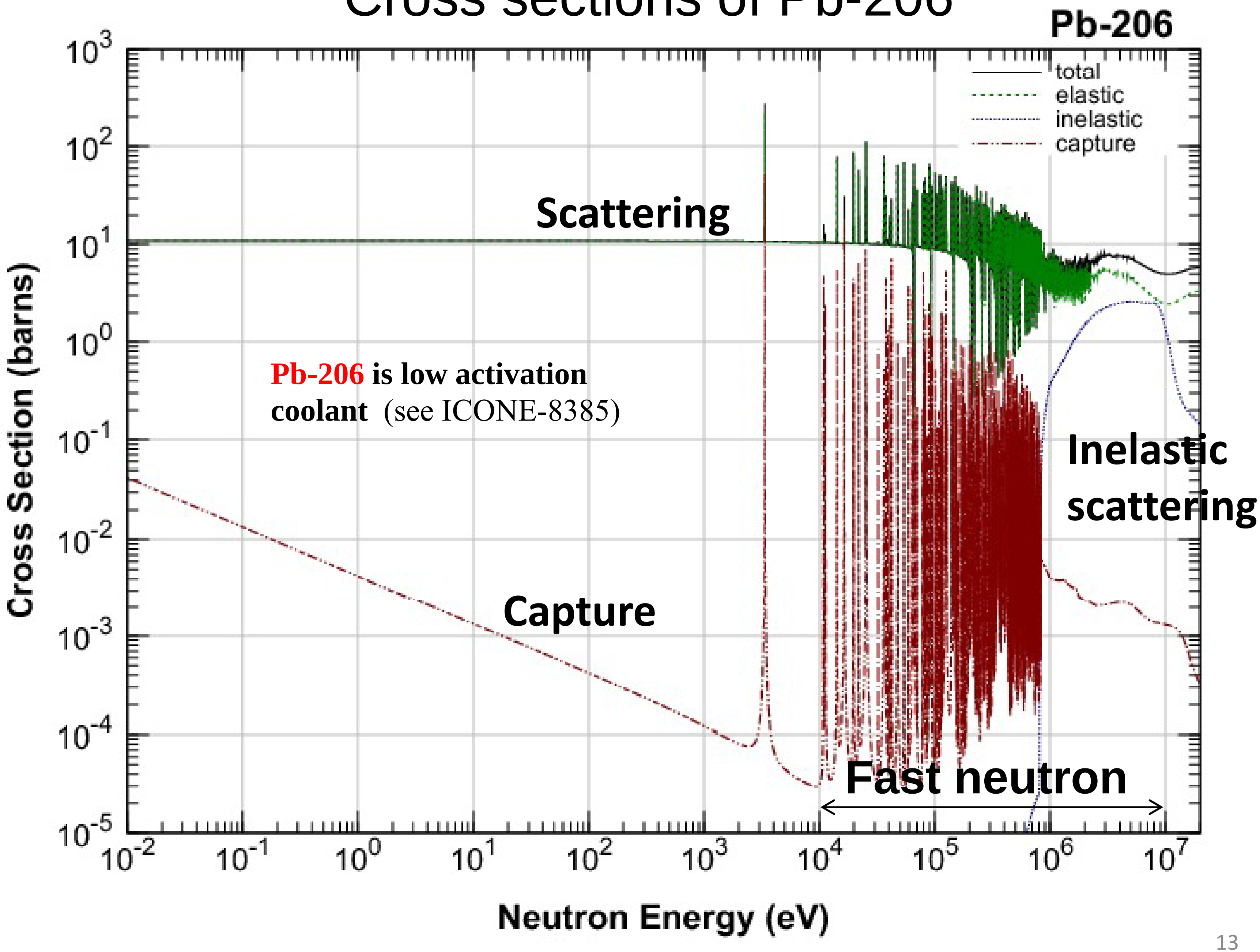


Cross sections of Na-23



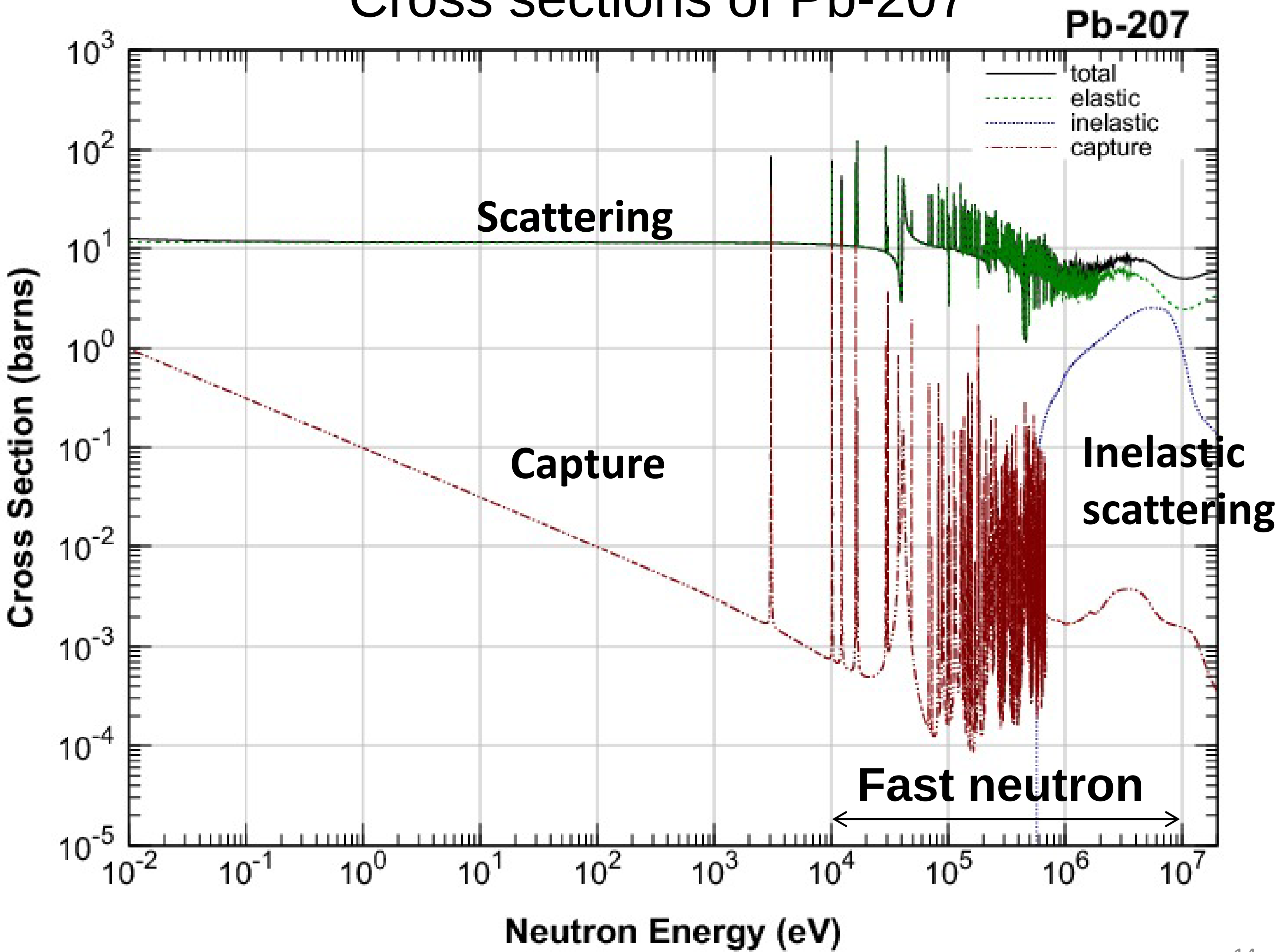
Ref. JENDL-4.0 (http://wwwndc.jaea.go.jp/jendl/j40/J40_J.html)

Cross sections of Pb-206



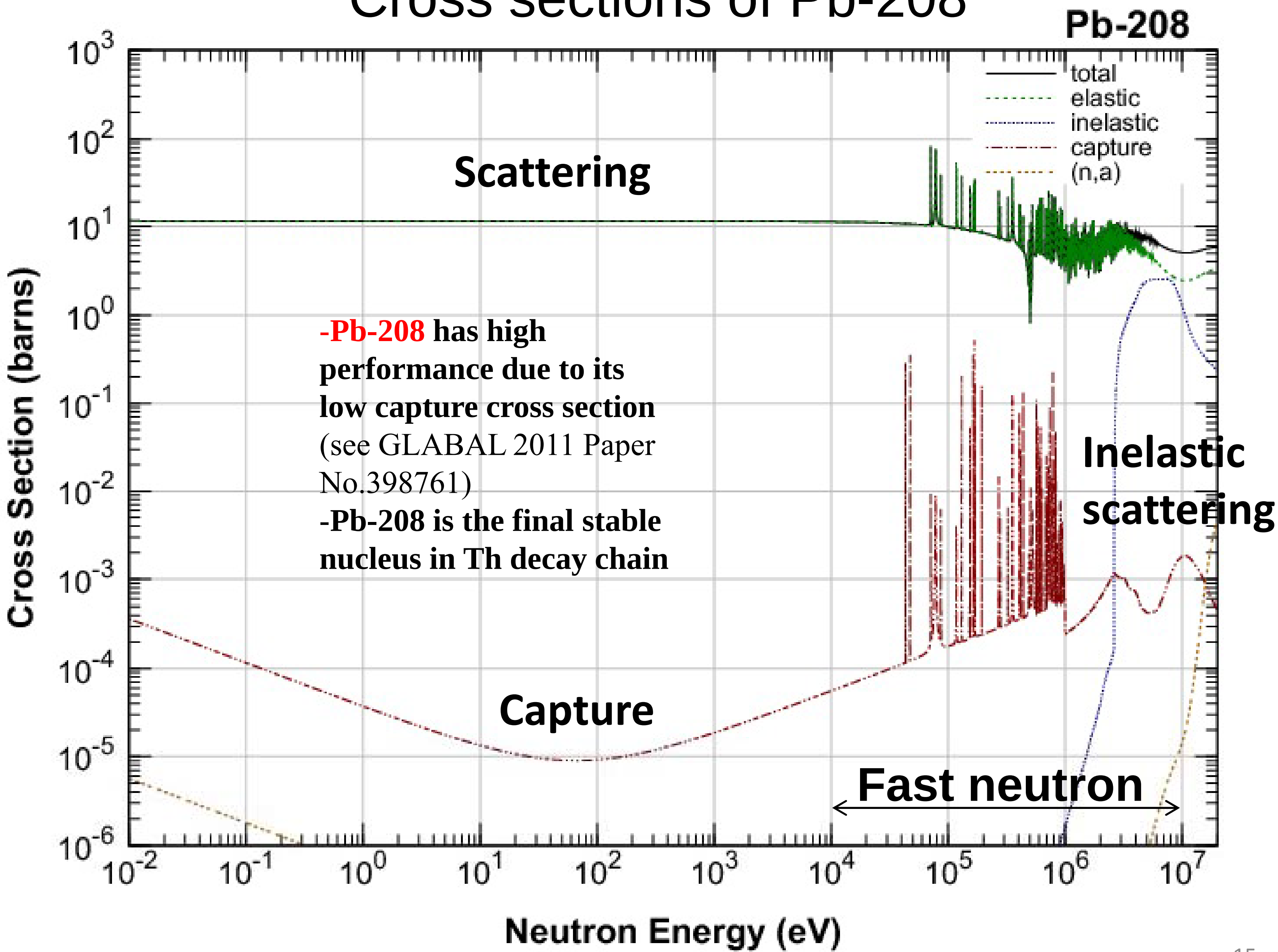
Ref. JENDL-4.0 (http://wwwndc.jaea.go.jp/jendl/j40/J40_J.html)

Cross sections of Pb-207



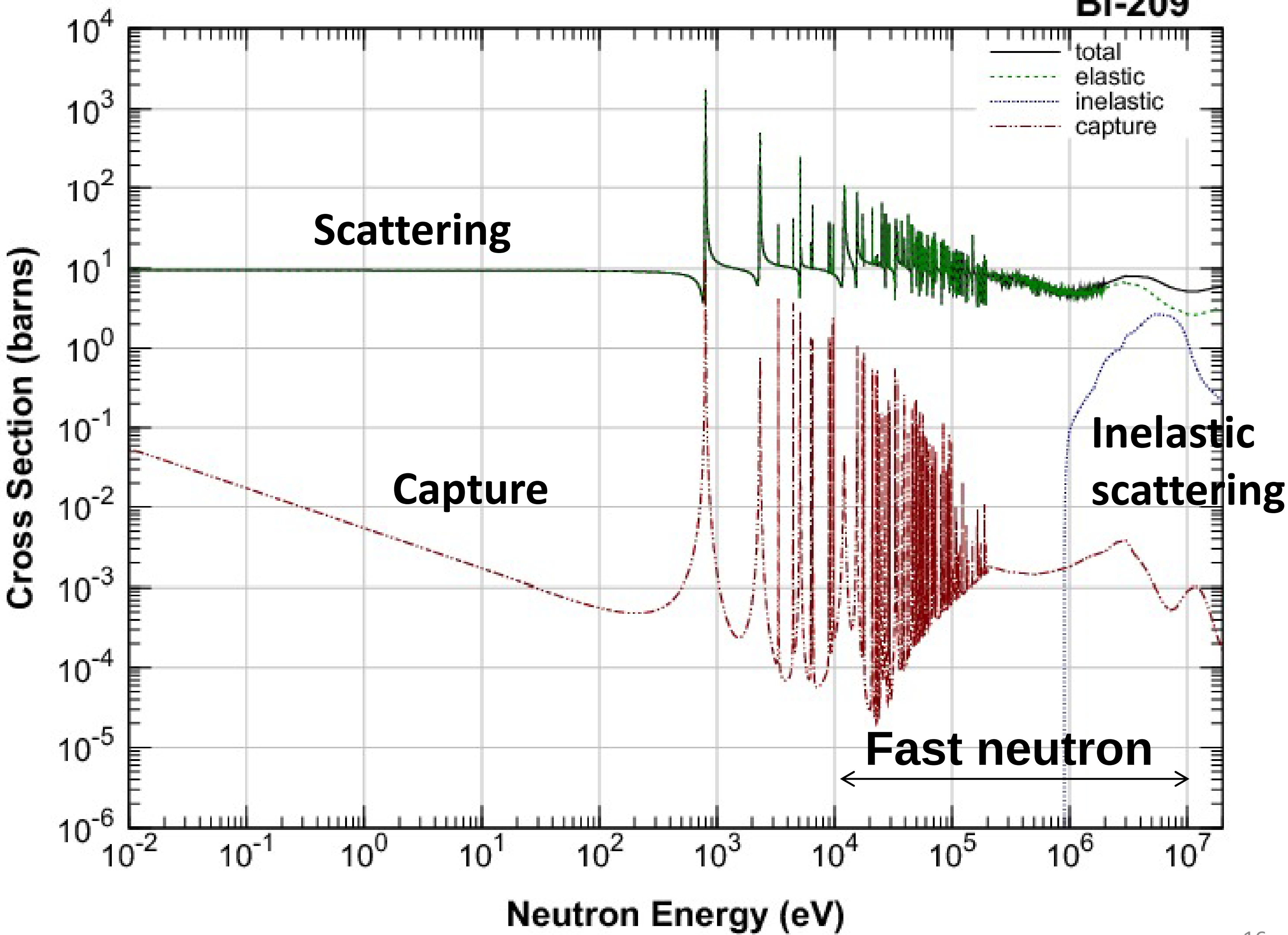
Ref. JENDL-4.0 (http://wwwndc.jaea.go.jp/jendl/j40/J40_J.html)

Cross sections of Pb-208



Ref. JENDL-4.0 (http://wwwndc.jaea.go.jp/jendl/j40/J40_J.html)

Cross sections of Bi-209



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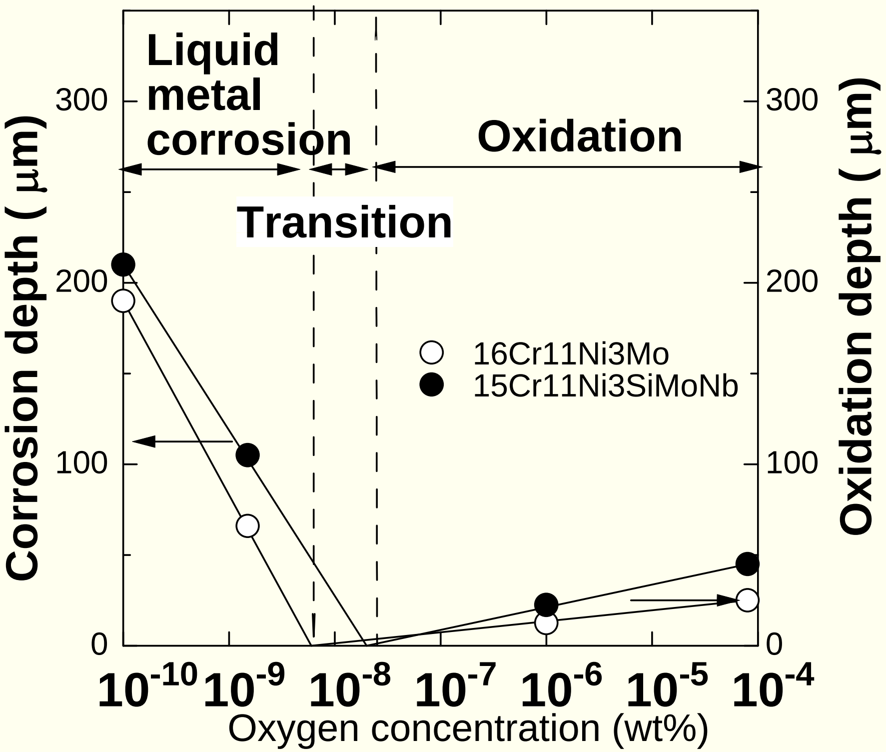
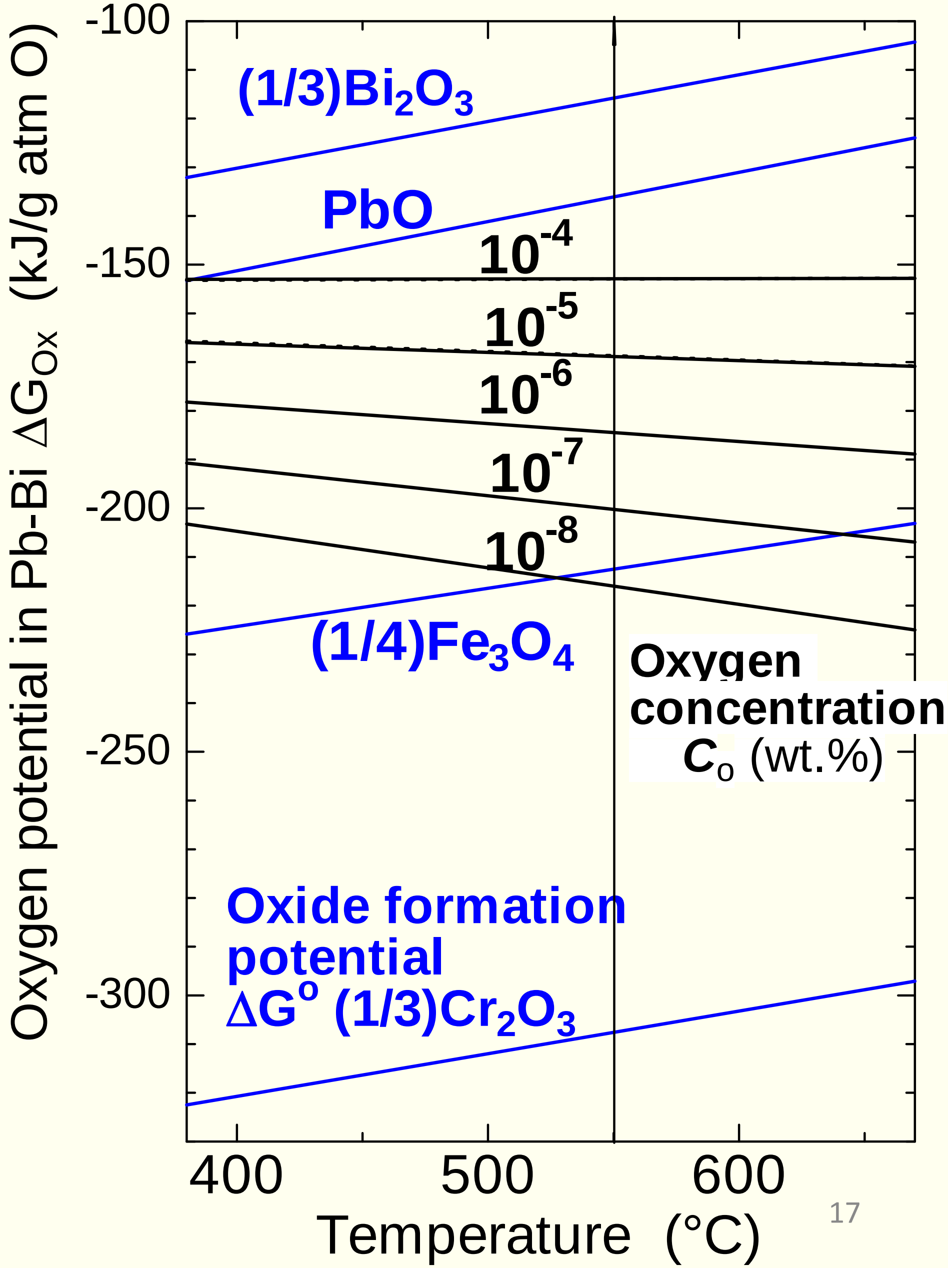
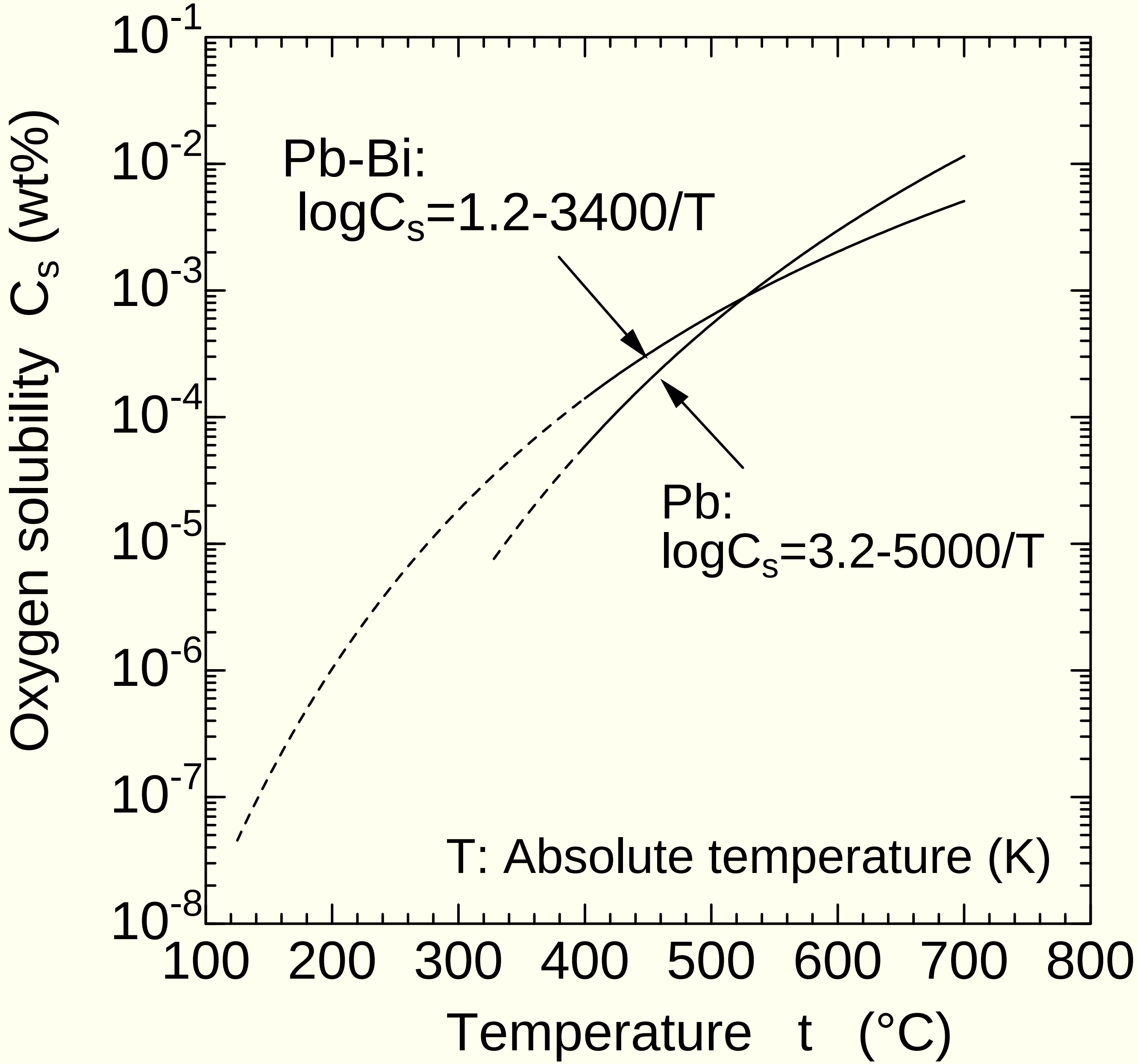
Dependence of Corrosion Rate on Oxygen Concentration in Pb and Pb-Bi

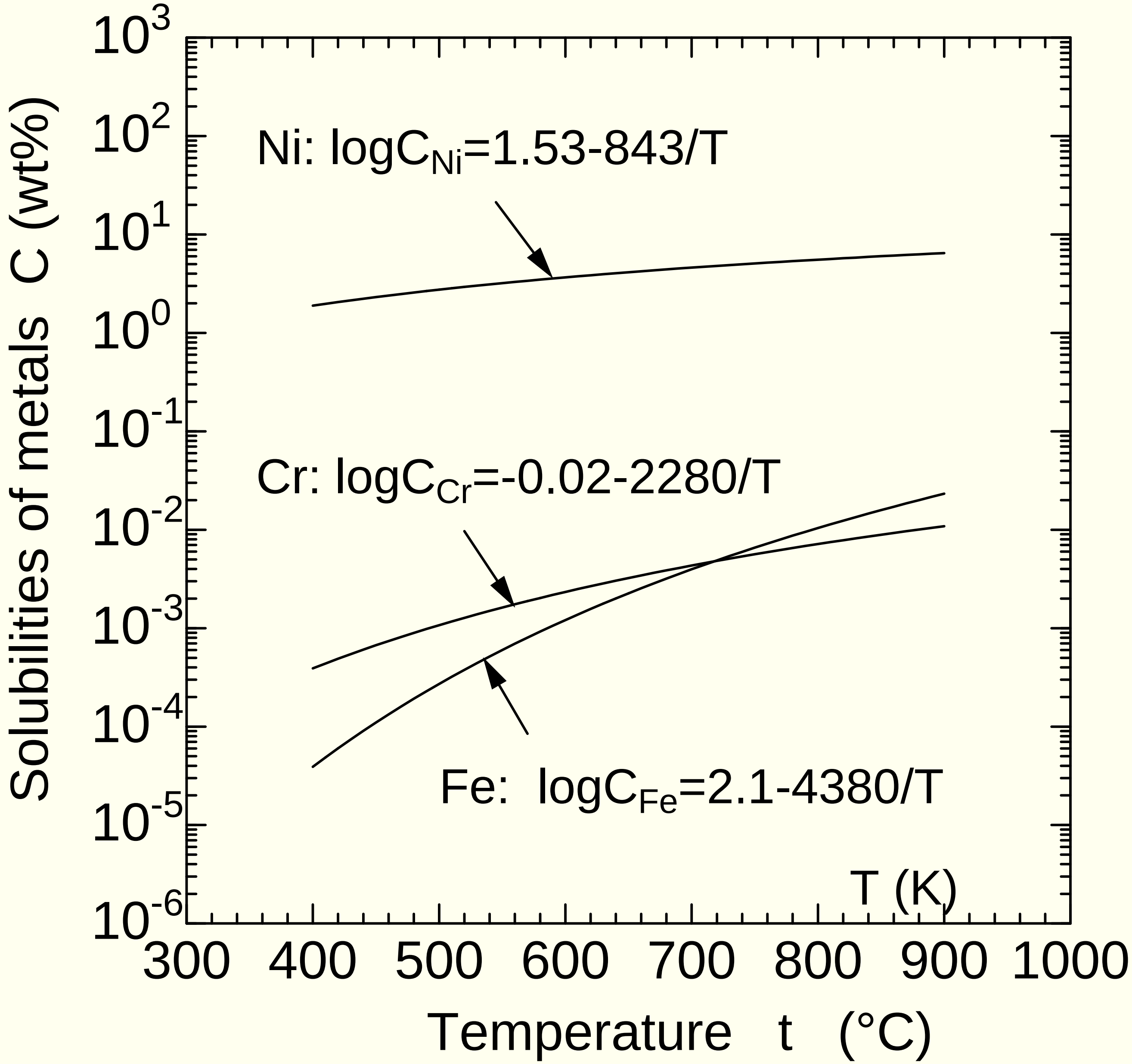




Solubility of Oxygen in Pb and 45%Pb-55%Bi



Solubility of Ni, Cr and Fe in Pb-Bi



Formation of oxides

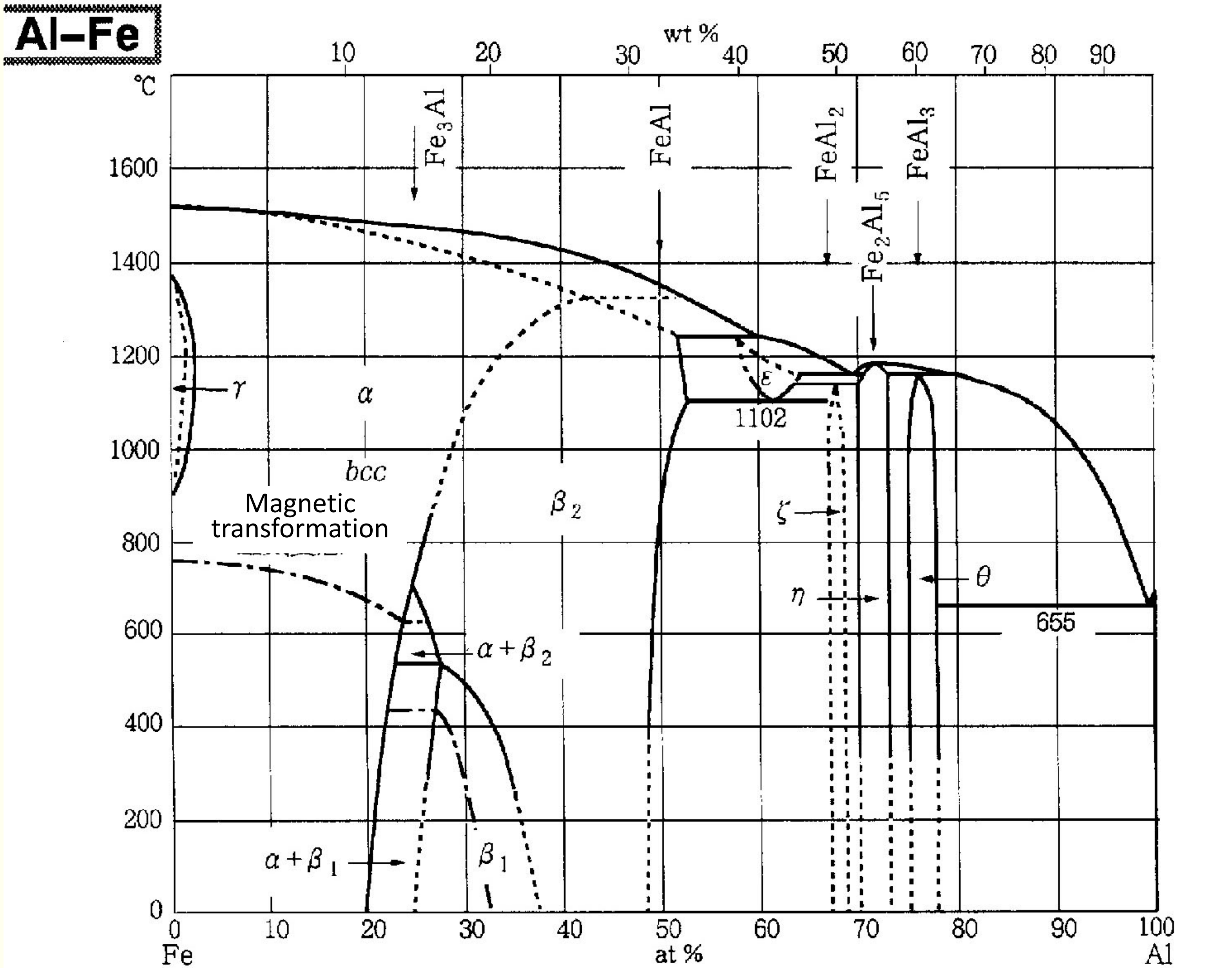
$$2Pb + O_2 \rightarrow 2PbO$$

$$4Bi + 3O_2 \rightarrow 2Bi_2O_3$$

$$Bi_2O_3 + 3Pb \rightarrow 3PbO + 2Bi$$

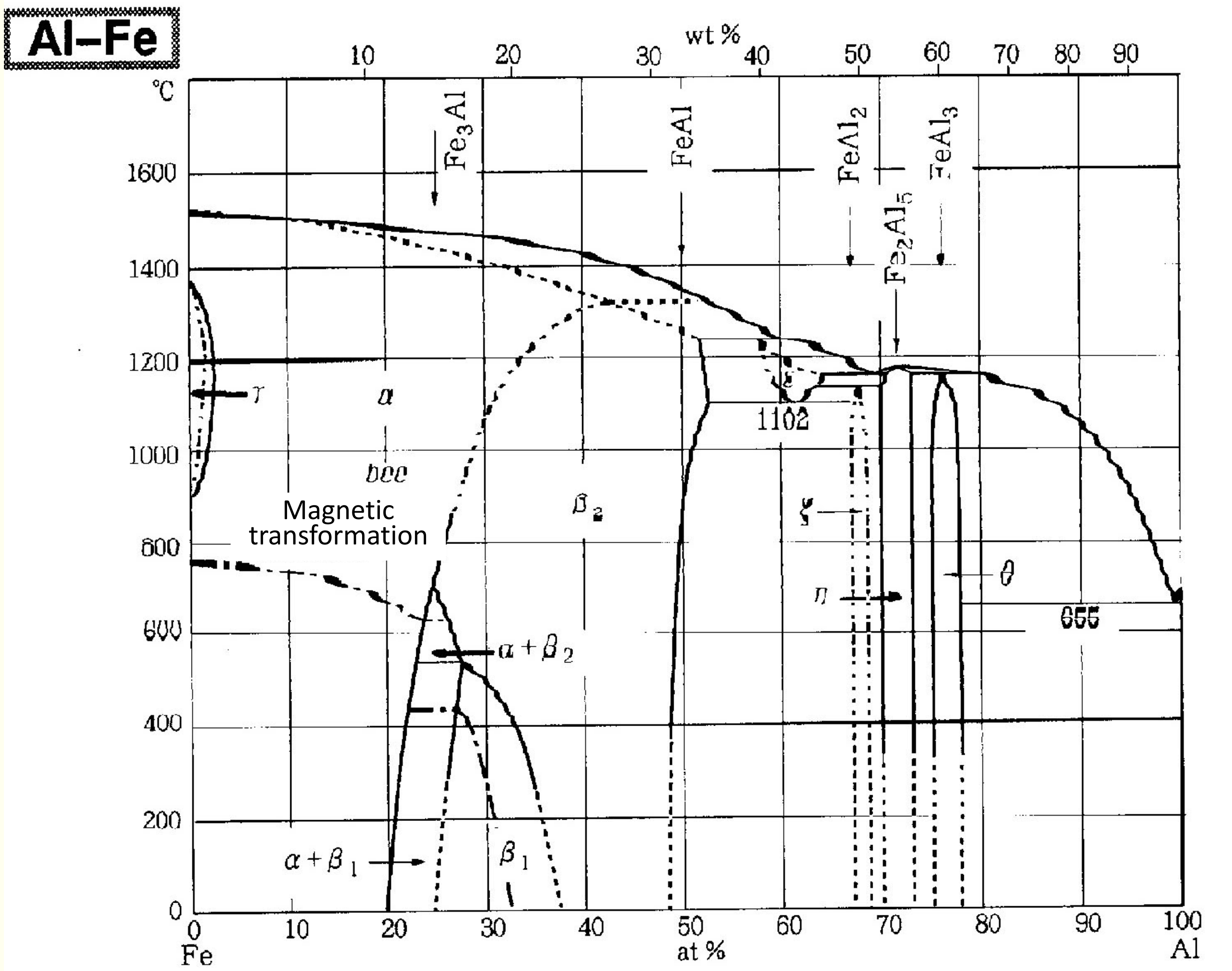
$$Pb + H_2O \rightarrow PbO + H_2$$

Reaction of Al layer with Fe for corrosion resistance



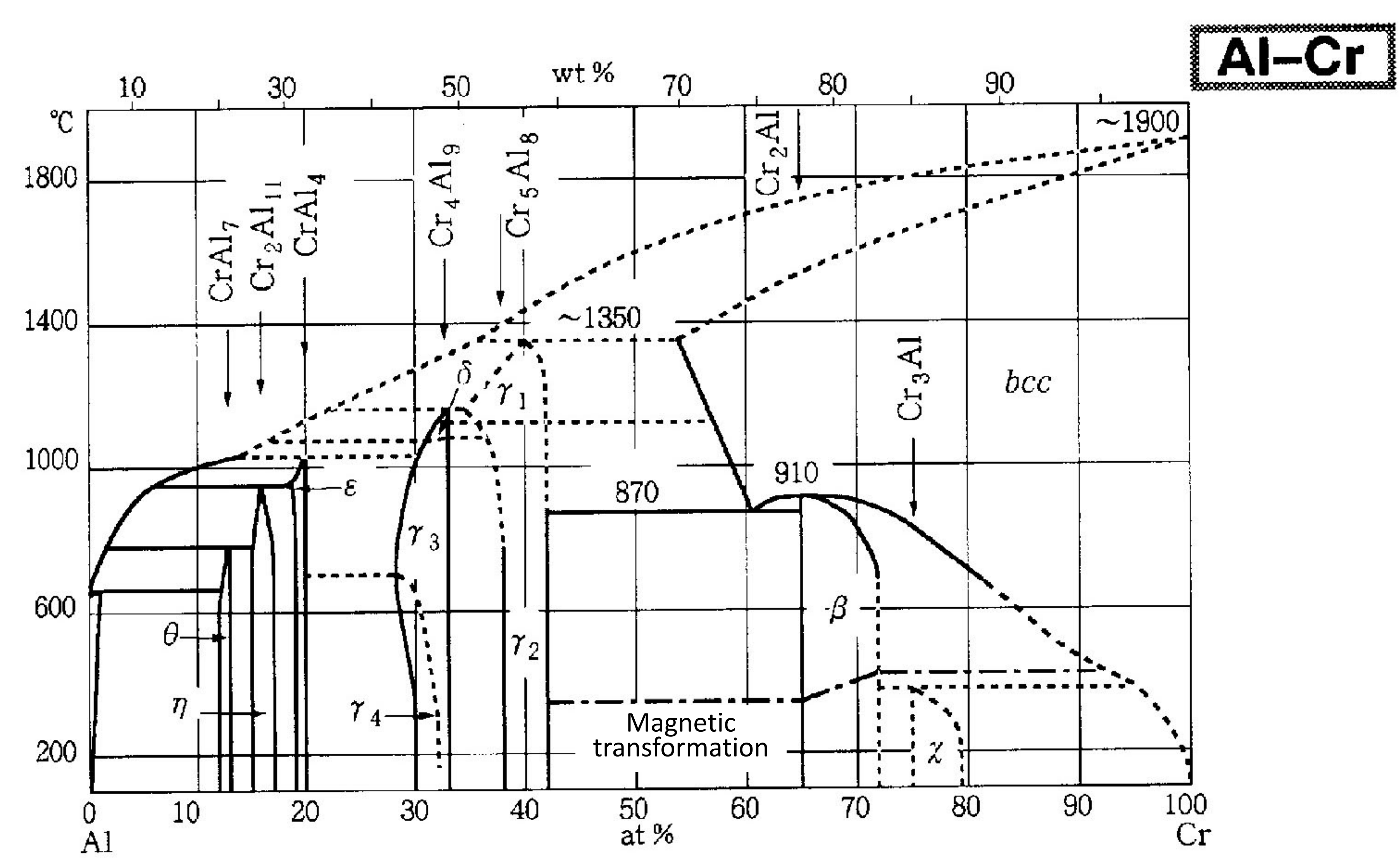
Ref. Nigen Gokin Jotaizu Shu, AGNE Gijutsu Center, 2001 (in Japanese)

Reaction of Al layer with Fe for corrosion resistance



Ref. Nigen Gokin Jotaizu Shu, AGNE Gijutsu Center, 2001 (in Japanese)

Reaction of Al layer with Cr for corrosion resistance



Ref. Nigen Gokin Jotaizu Shu, AGNE Gijutsu Center, 2001 (in Japanese)

Dependence of Oxygen Solubility in γ-Fe, δ-Fe and Liquid Phase on Oxygen Partial Pressure

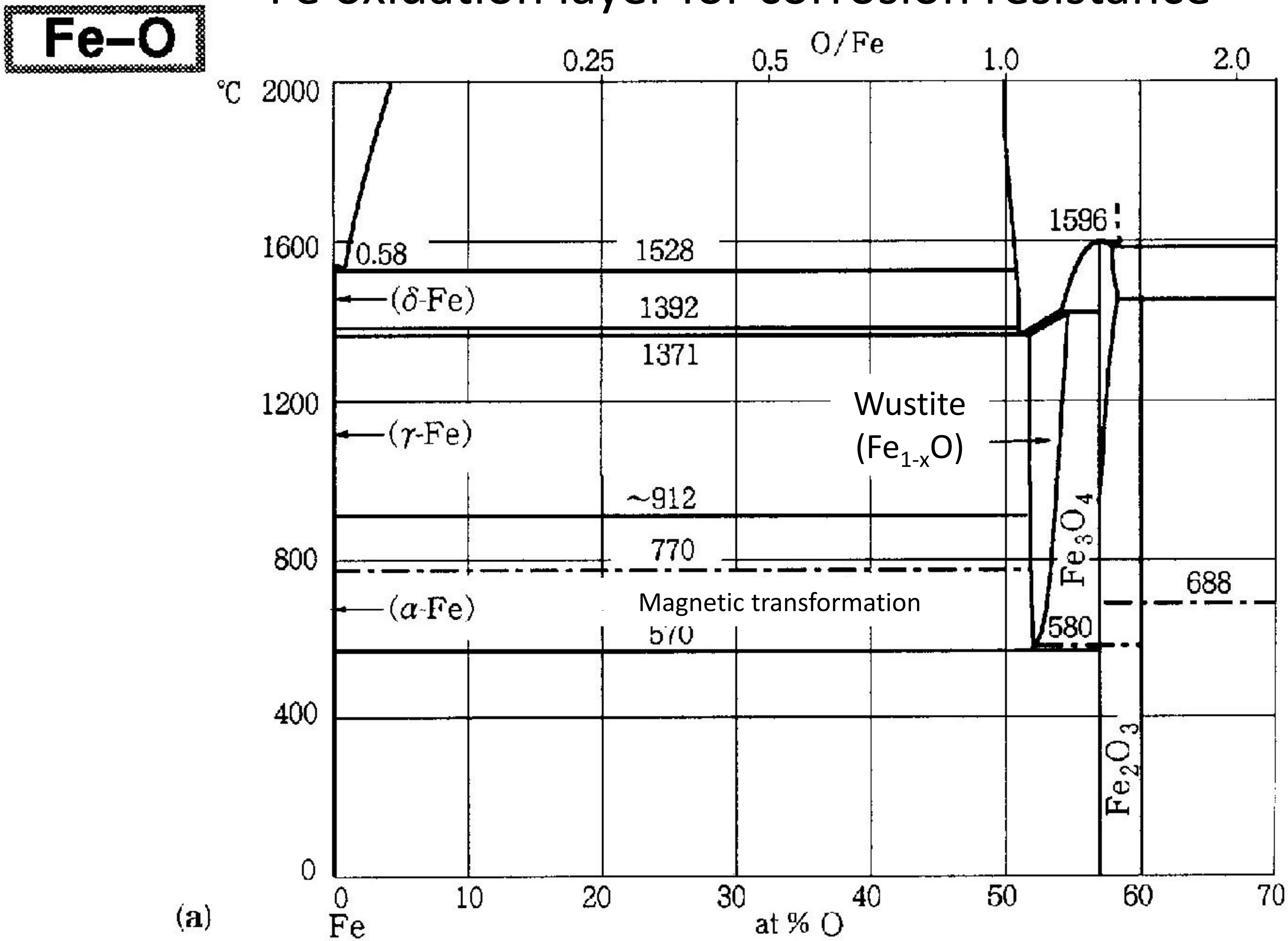
$$\log C_{\mathrm{o}}(\mathrm{at\%}) = 0.5\log P_{\mathrm{o}_2} - 5.12 + 9150/T \qquad (900-1391°\mathrm{C})$$

$$\log C_{\mathrm{o}}(\mathrm{at\%}) = 0.5\log P_{\mathrm{o}_2} - 4.15 + 8130/T \qquad (1391-1527°\mathrm{C})$$

$$\log C_{\mathrm{o}}(\mathrm{at\%}) = 0.5\log P_{\mathrm{o}_2} - 1.81 + 6120/T \qquad (1550-1700°\mathrm{C})$$

where P (Pa), T (K)

Fe oxidation layer for corrosion resistance



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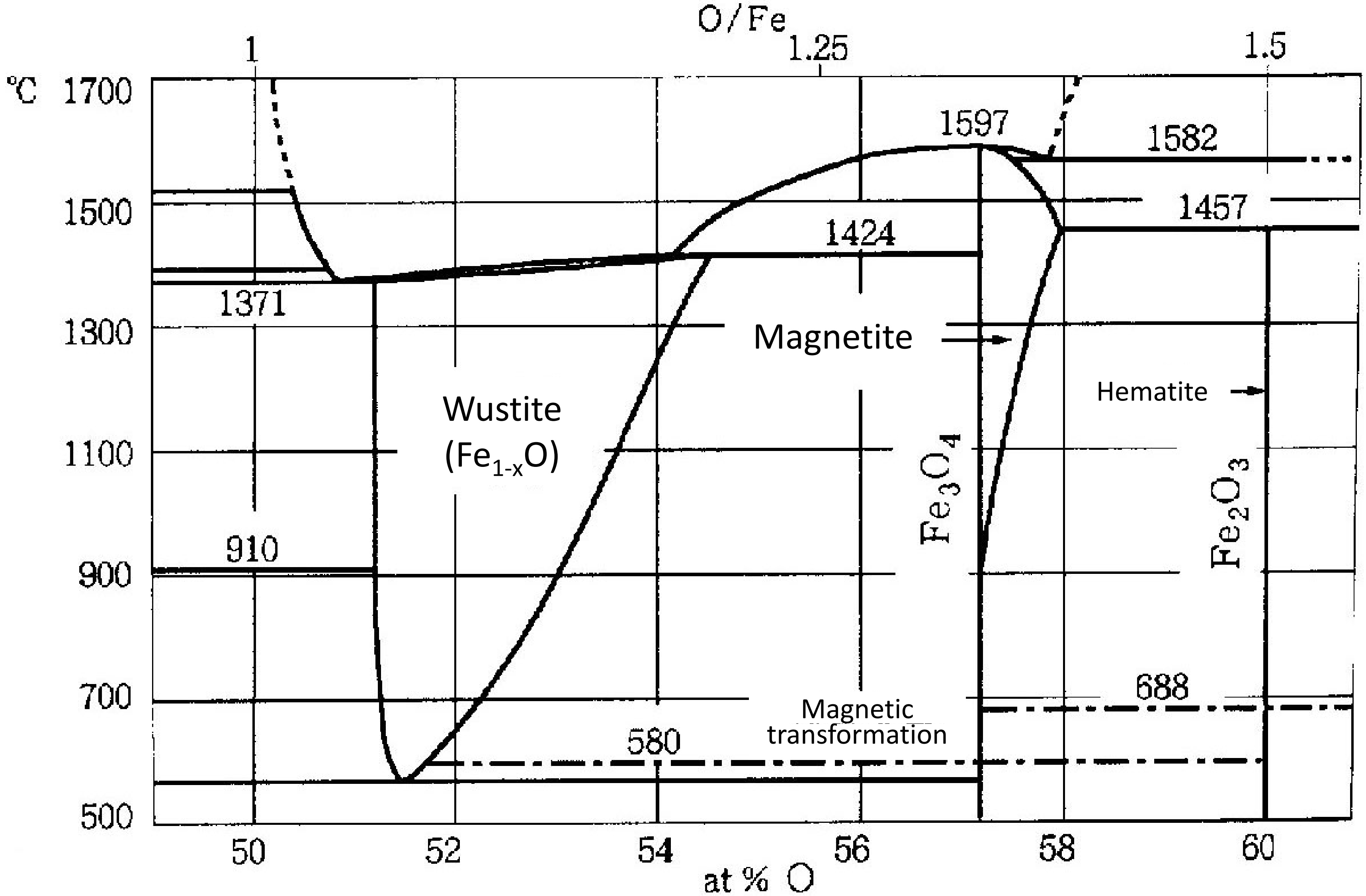
Fe oxidation layer for corrosion resistance



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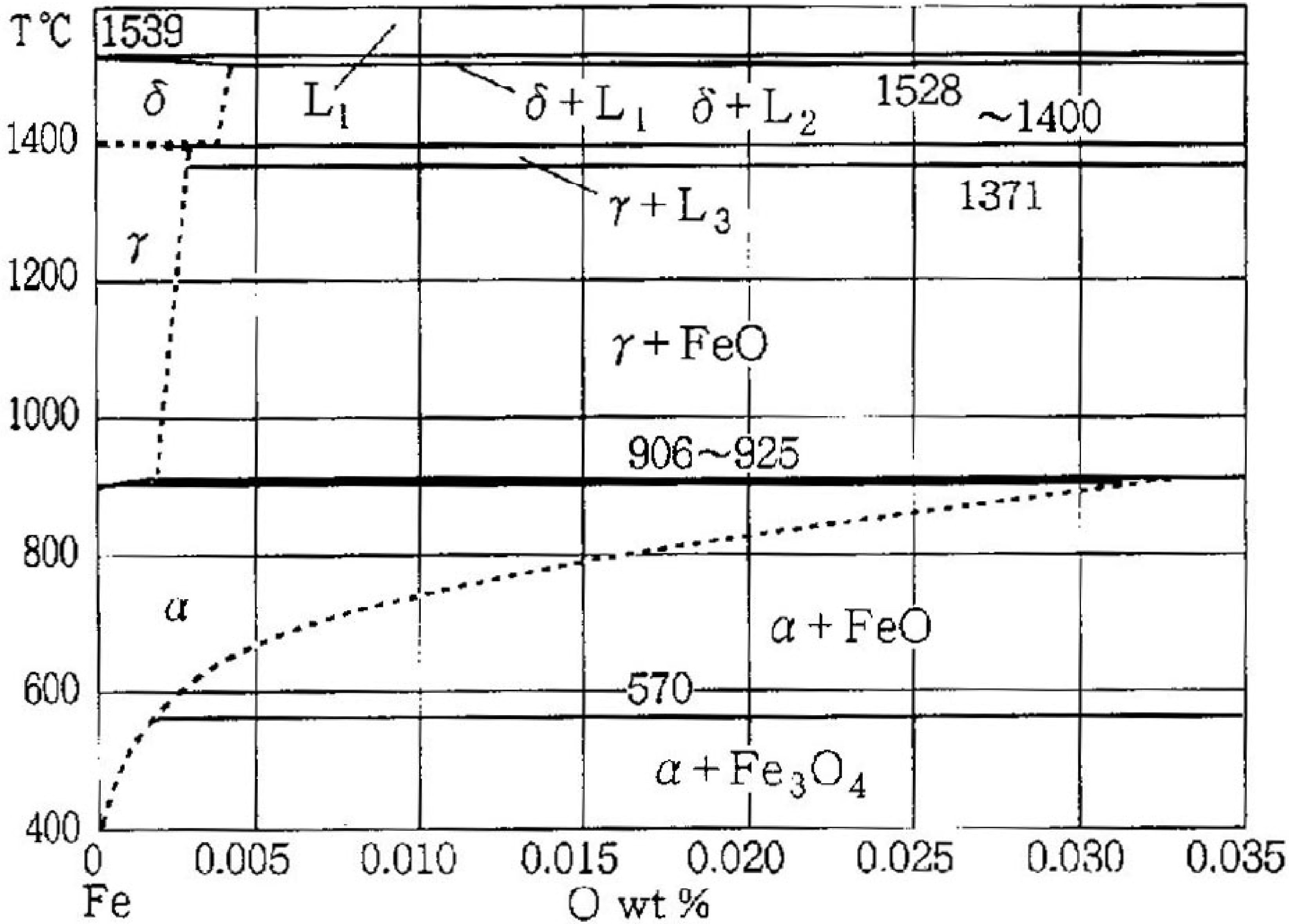
Fe oxidation layer for corrosion resistance



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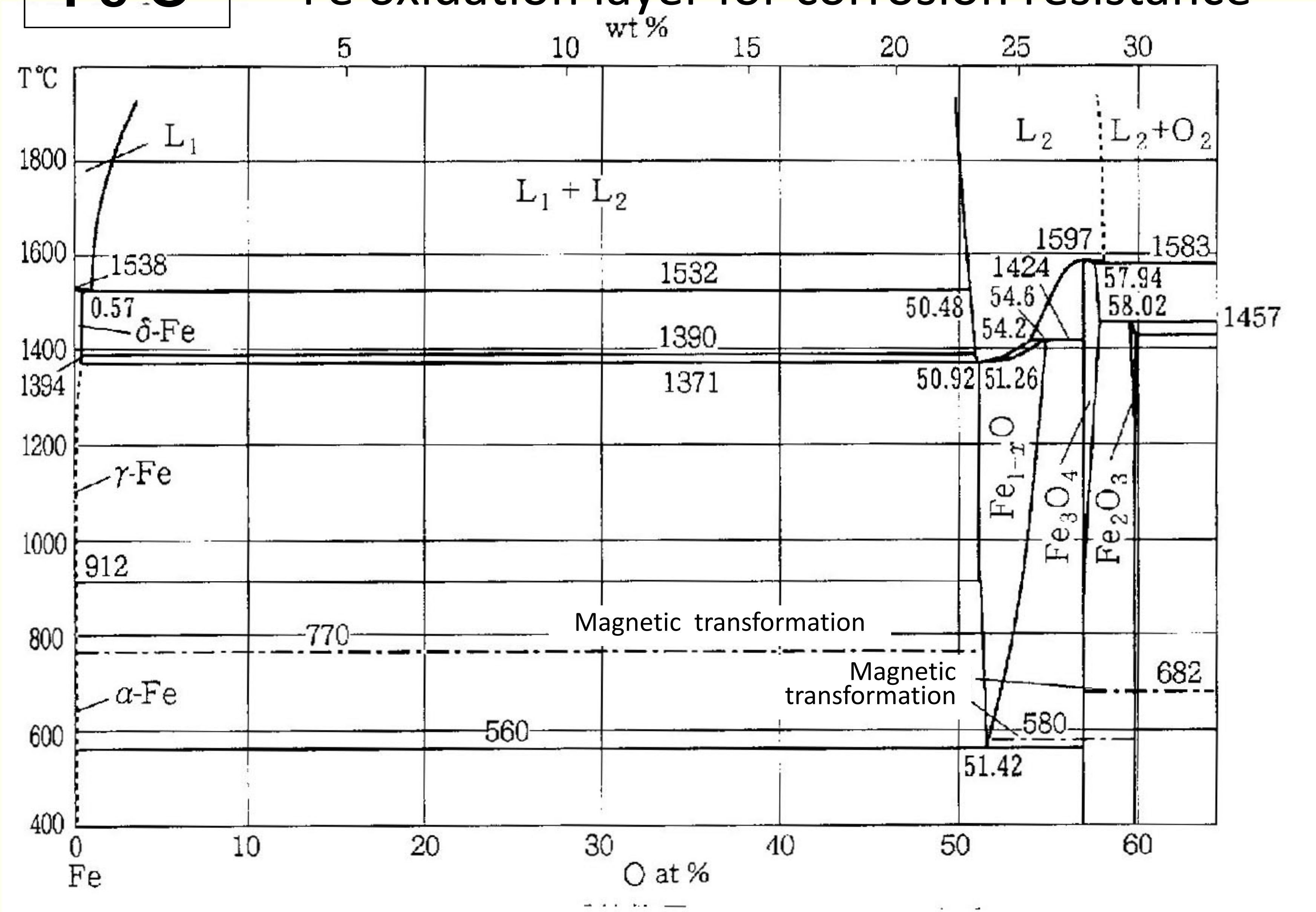
Fe-O Fe oxidation layer for corrosion resistance



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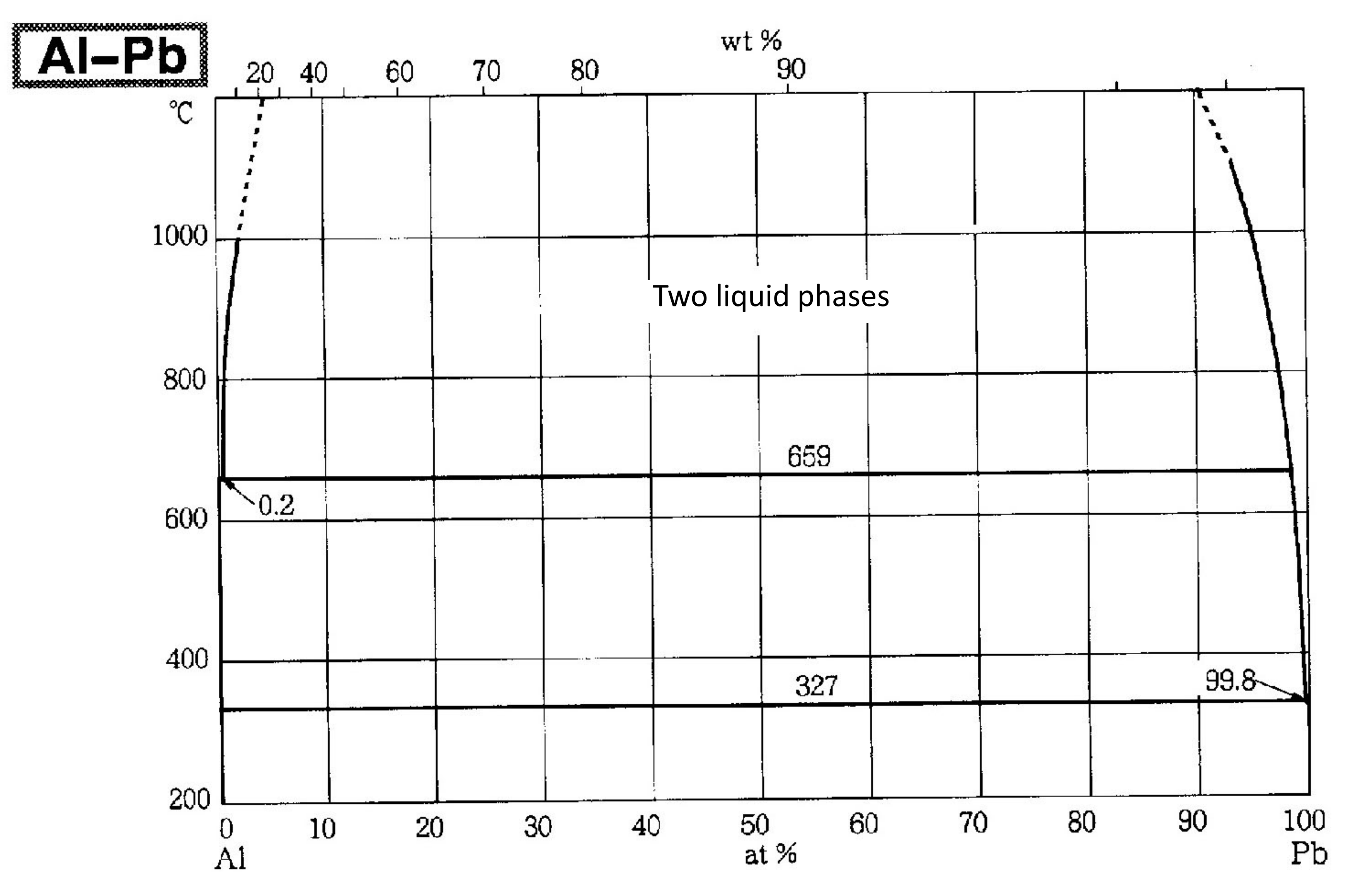
Reaction in Al coating for corrosion resistance



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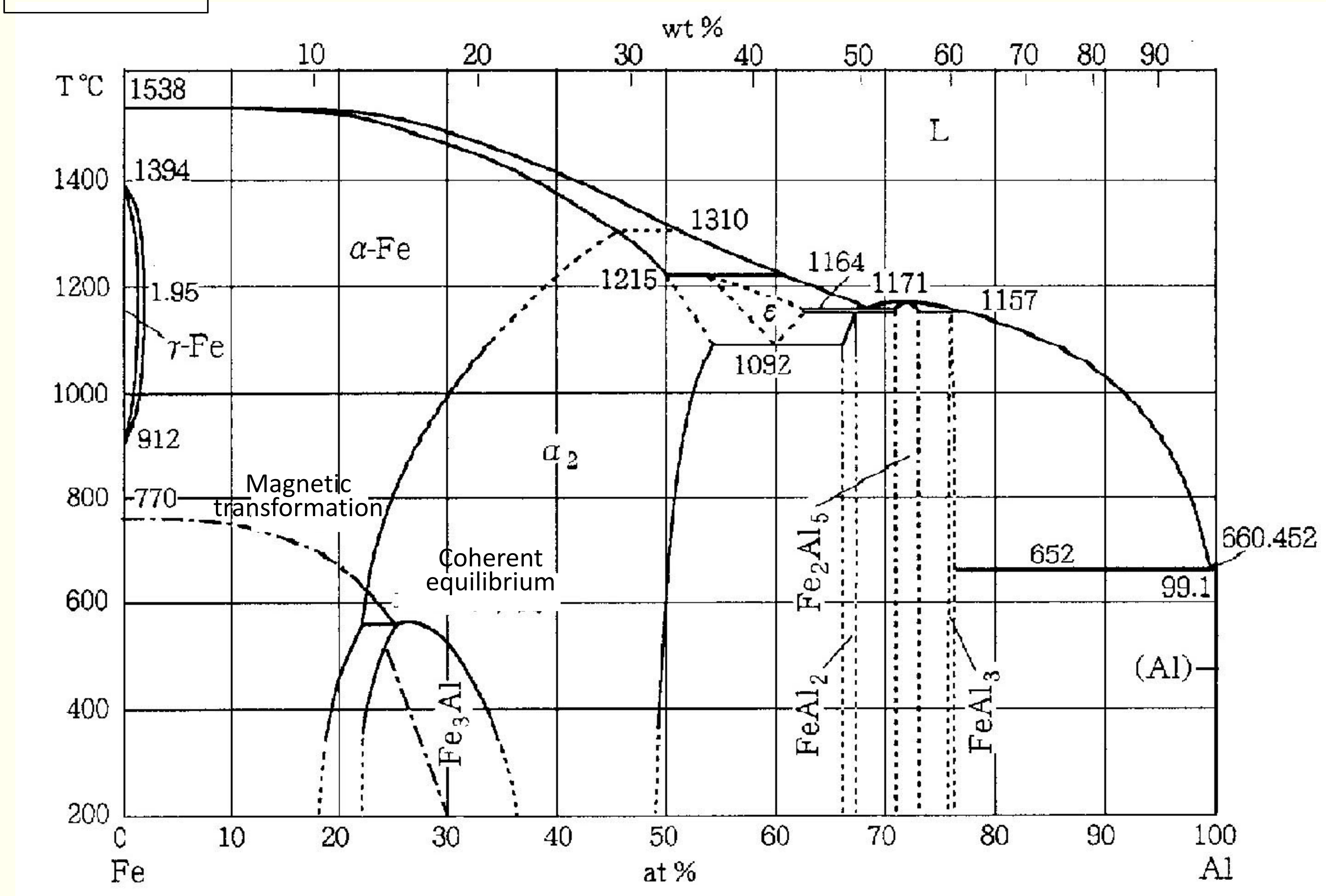
Fe-Al

Fe-Al alloy coating for corrosion resistance



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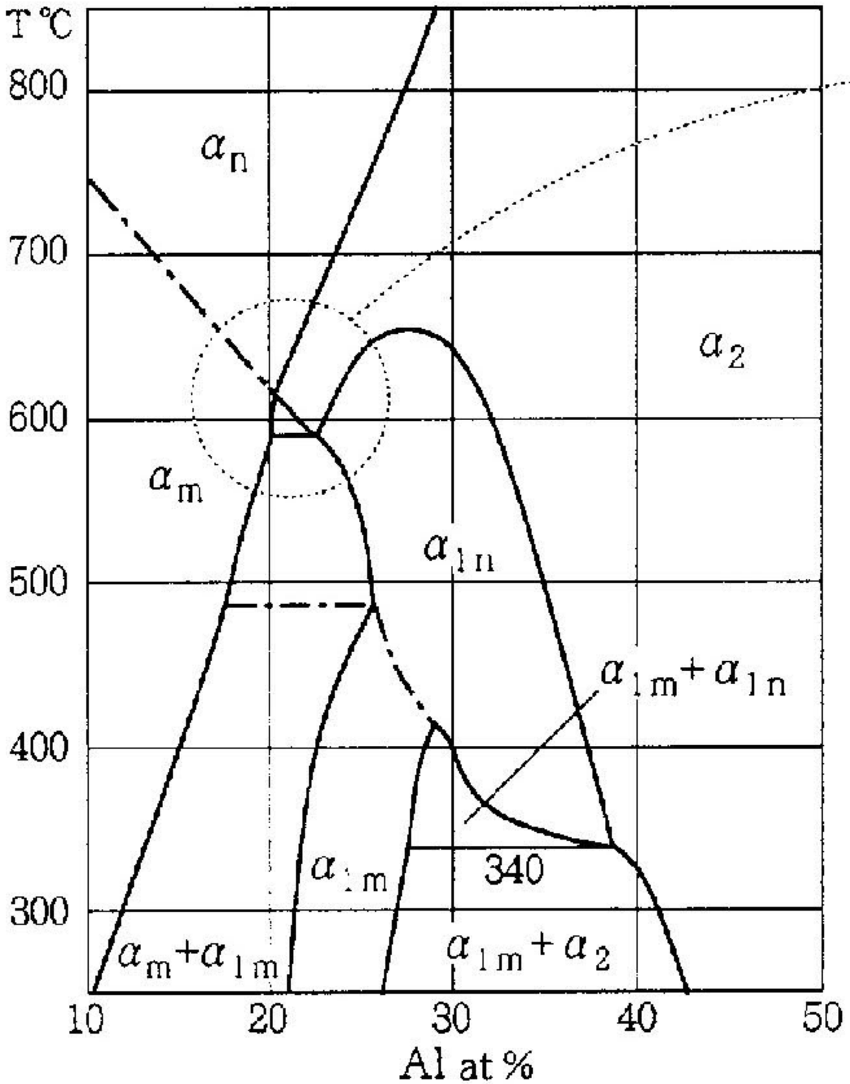
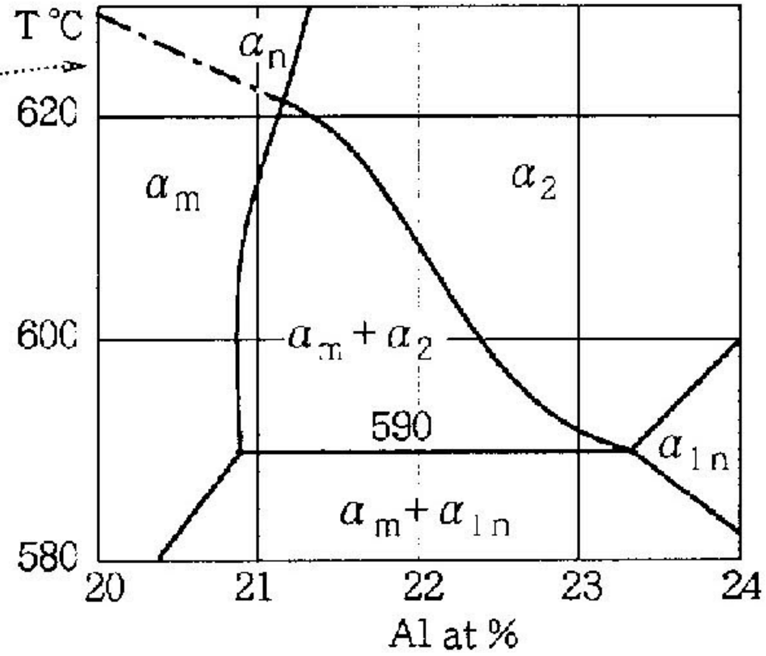
Fe-Al

Fe-Al alloy coating for corrosion resistance

Phase diagram of Fe - Al (10 - 50at%) system





α_m : α - Fe (ferromagnetic), α_n : α - Fe (paramagnetic)

α_2 : FeAl (B2 type), α_{1n} : Fe_3O_4 (paramagnetic)

α_{1m} : Fe_3Al (ferromagnetic)

Long and short dashed line :

Magnetic transformation temperature

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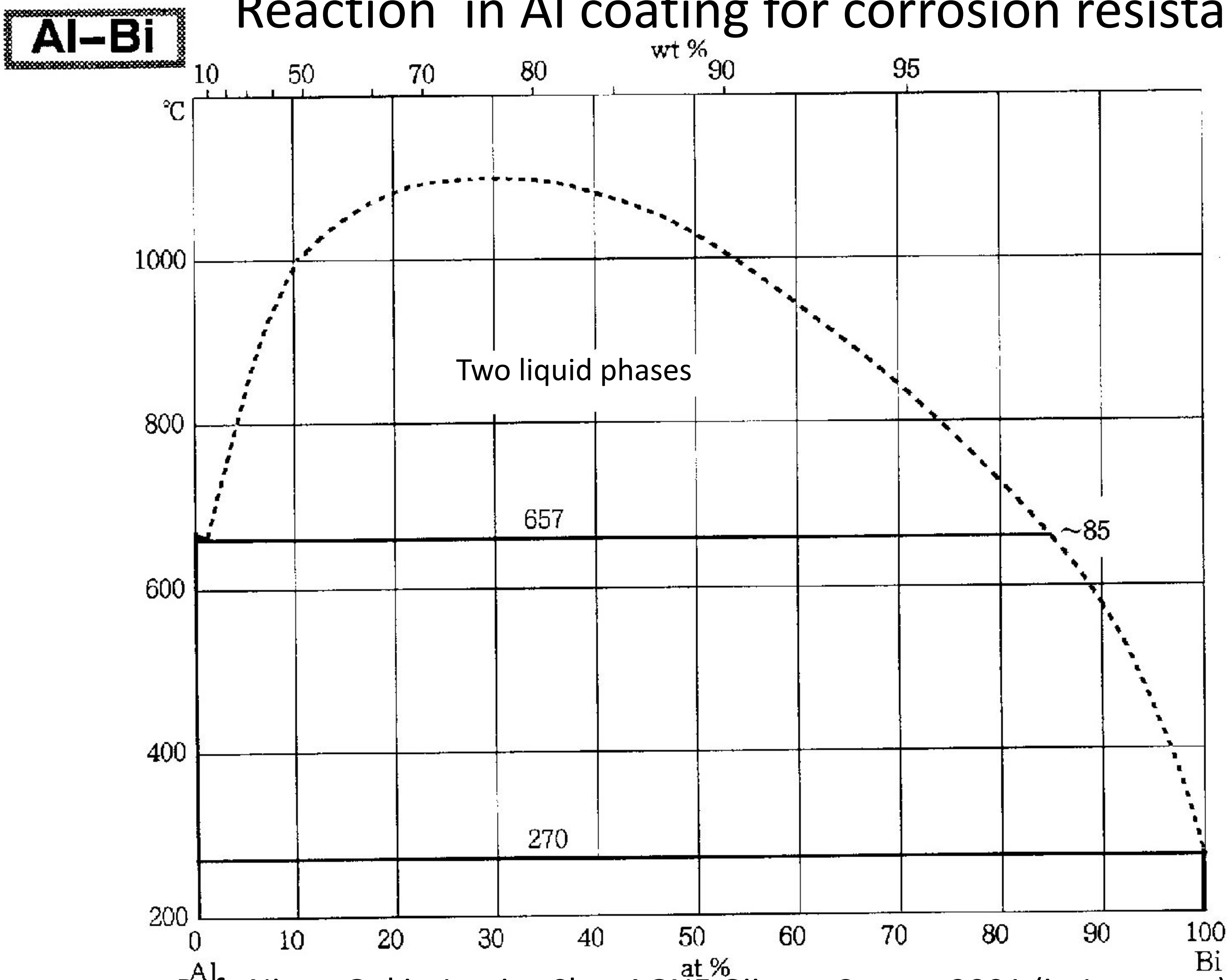
Reaction in Al coating for corrosion resistance



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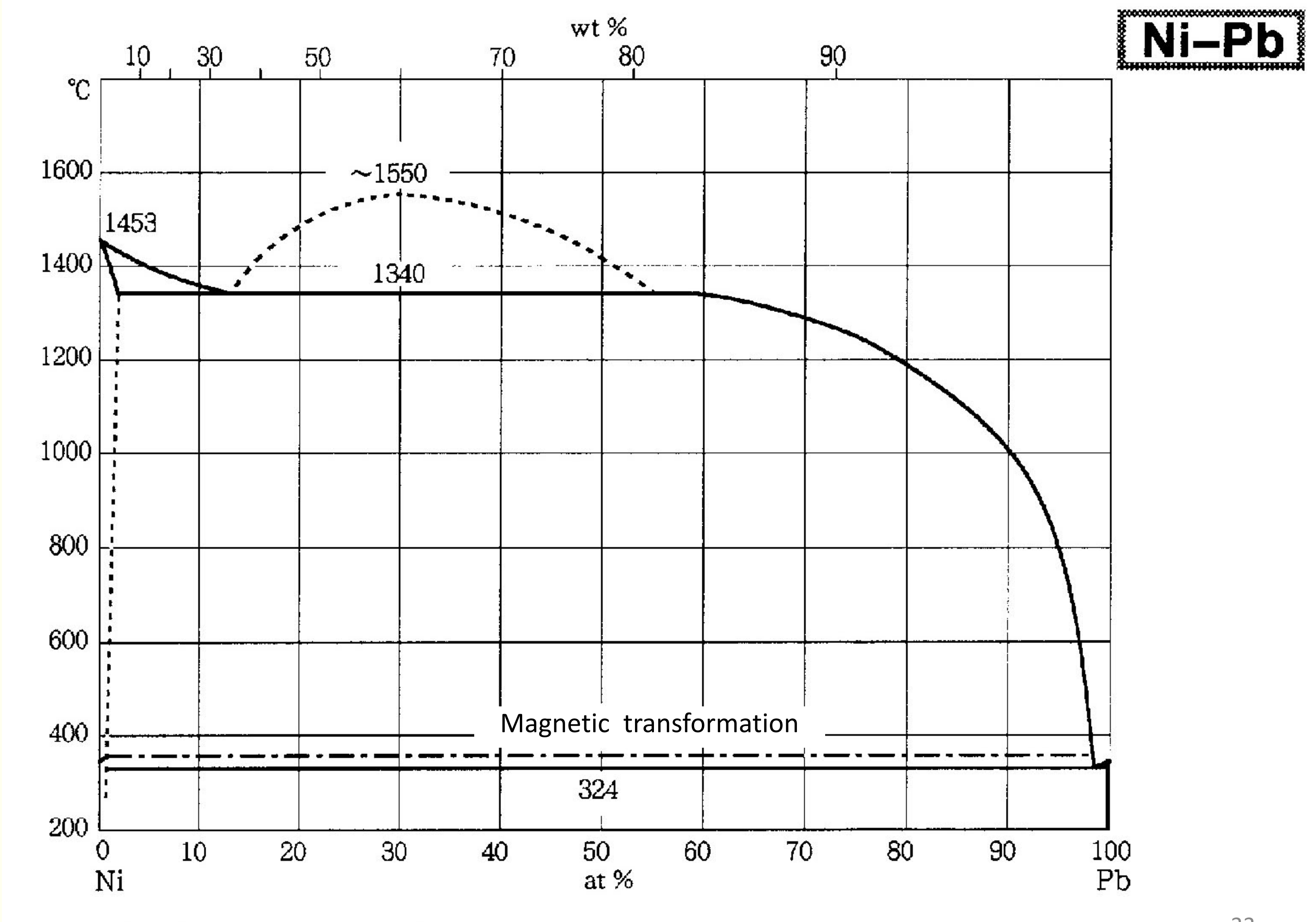
Solution of Ni in Pb



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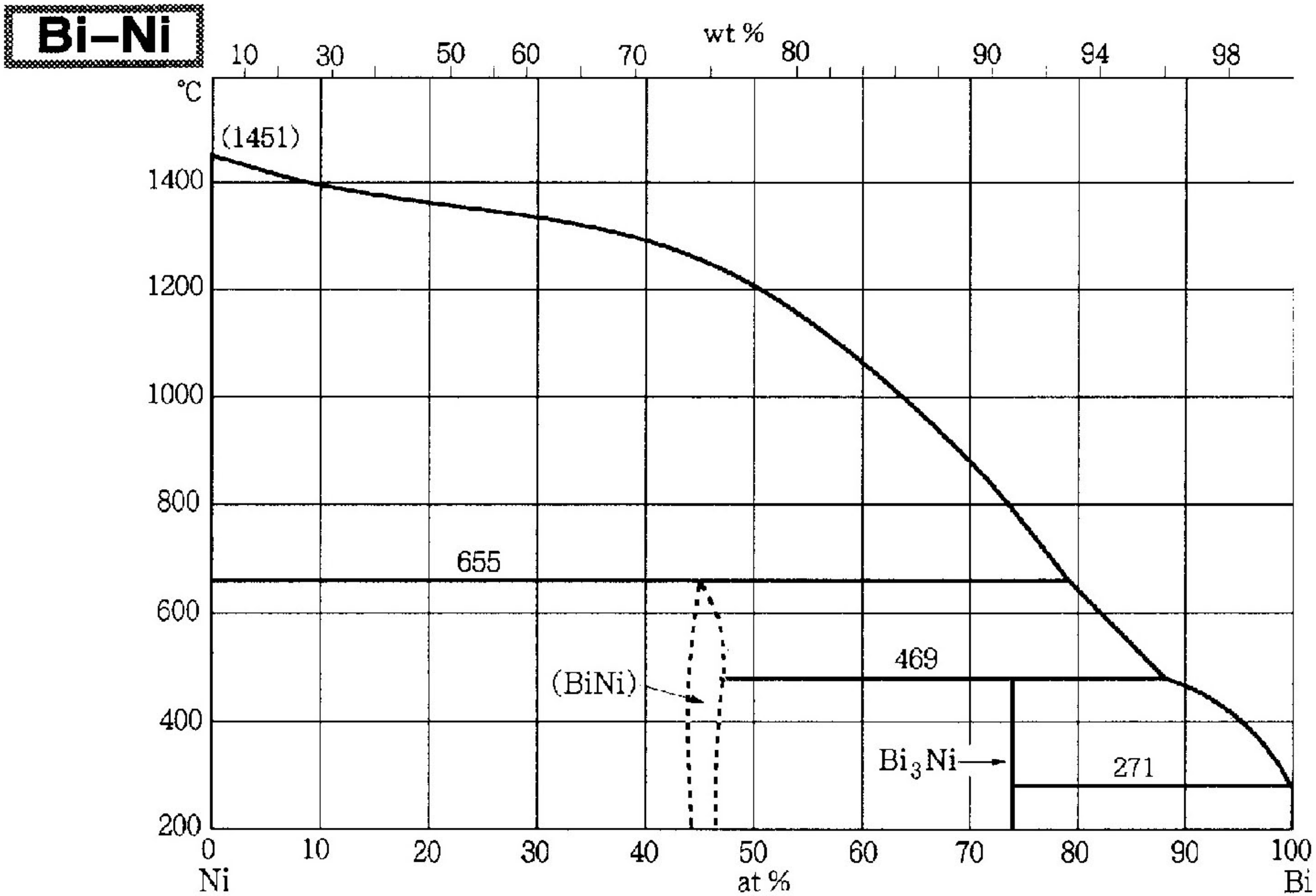
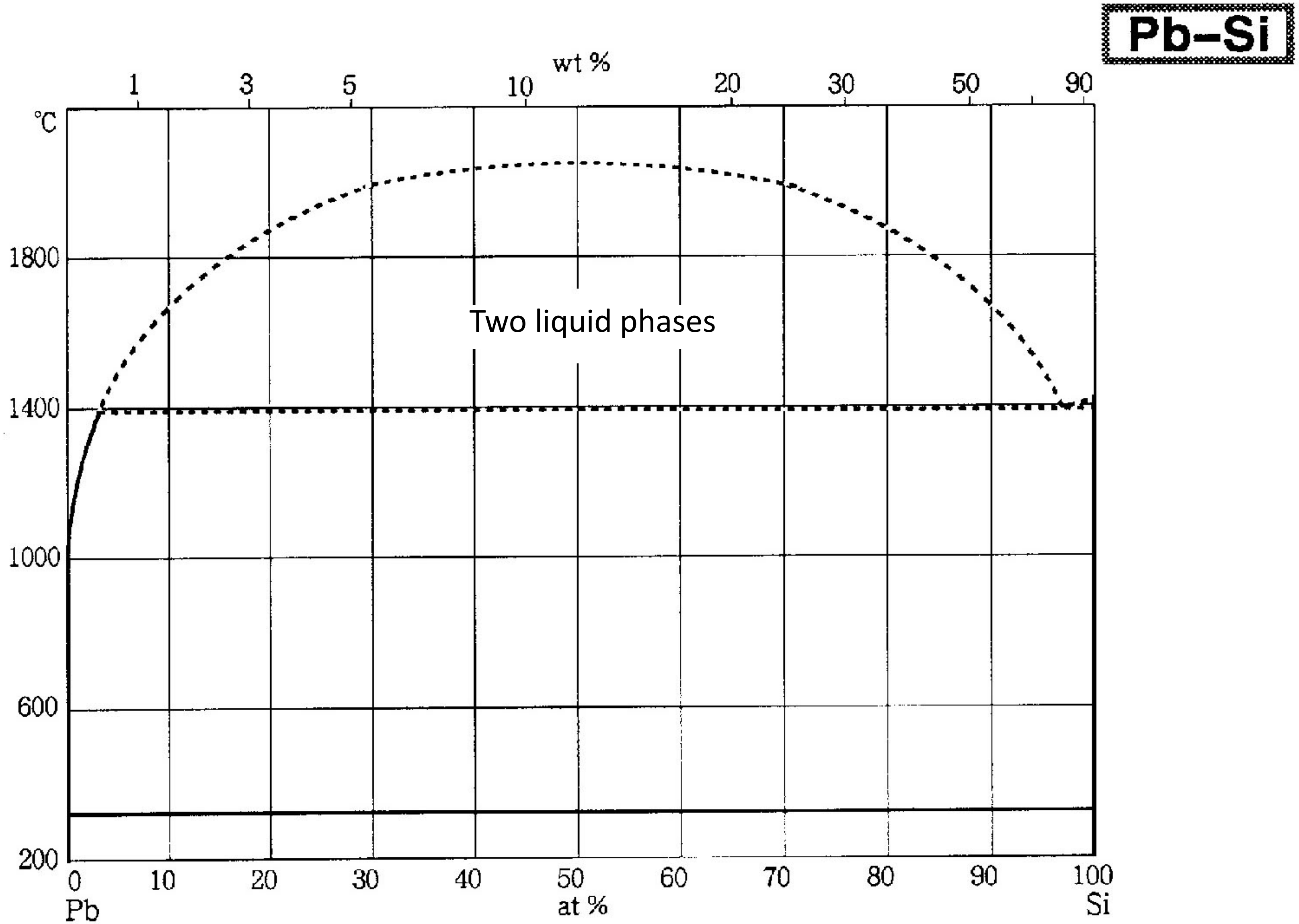
Solution of Ni in Bi



Ref. Nigen Gokin Jotaizu Shu, AGNE Gijutsu Center, 2001 (in Japanese)

Reaction of Si in Si oxide crucible with Pb



Monotectic reaction system

Ref. Nigen Gokin Jotaizu Shu, AGNE Gijutsu Center, 2001 (in Japanese)