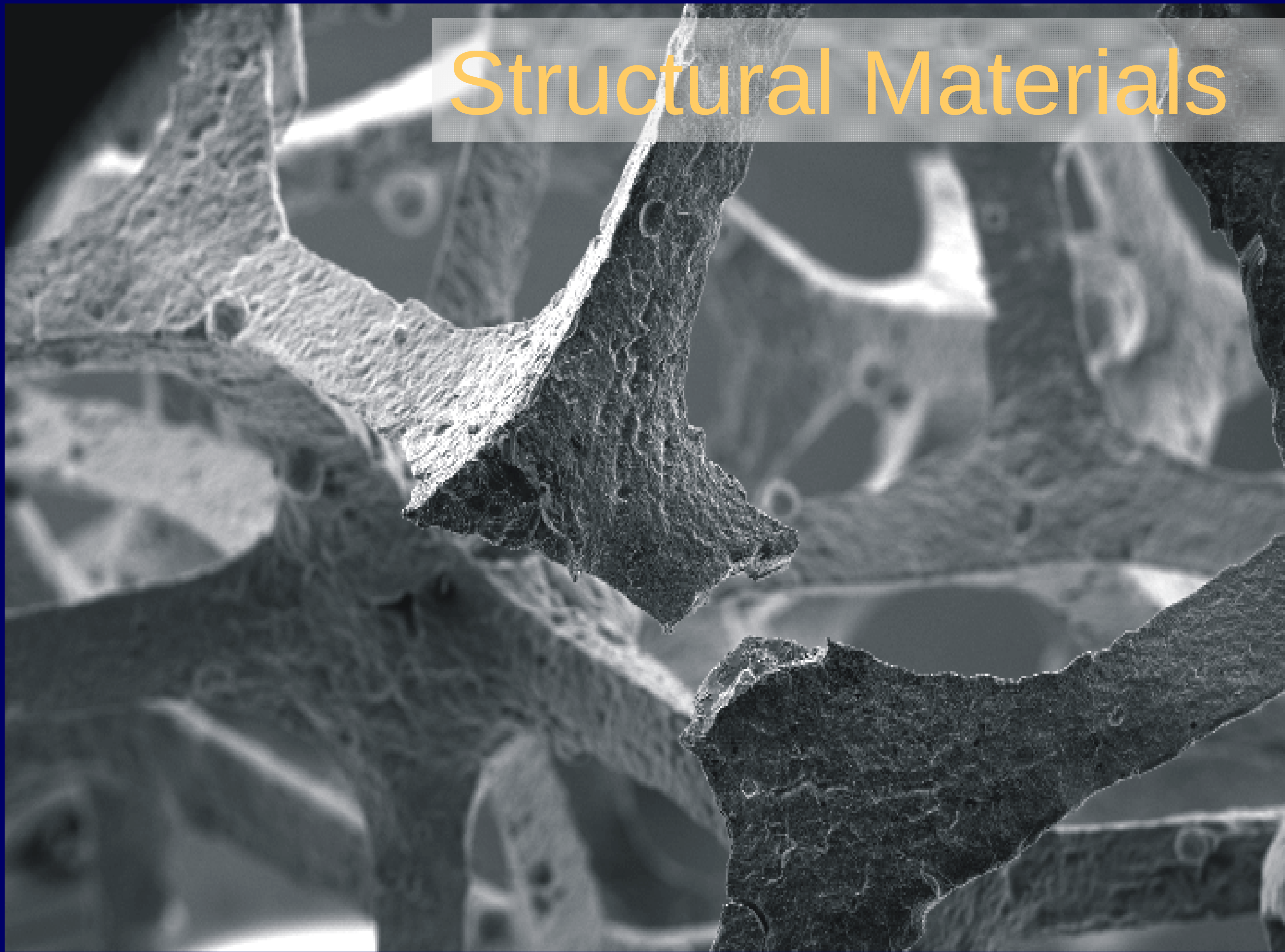
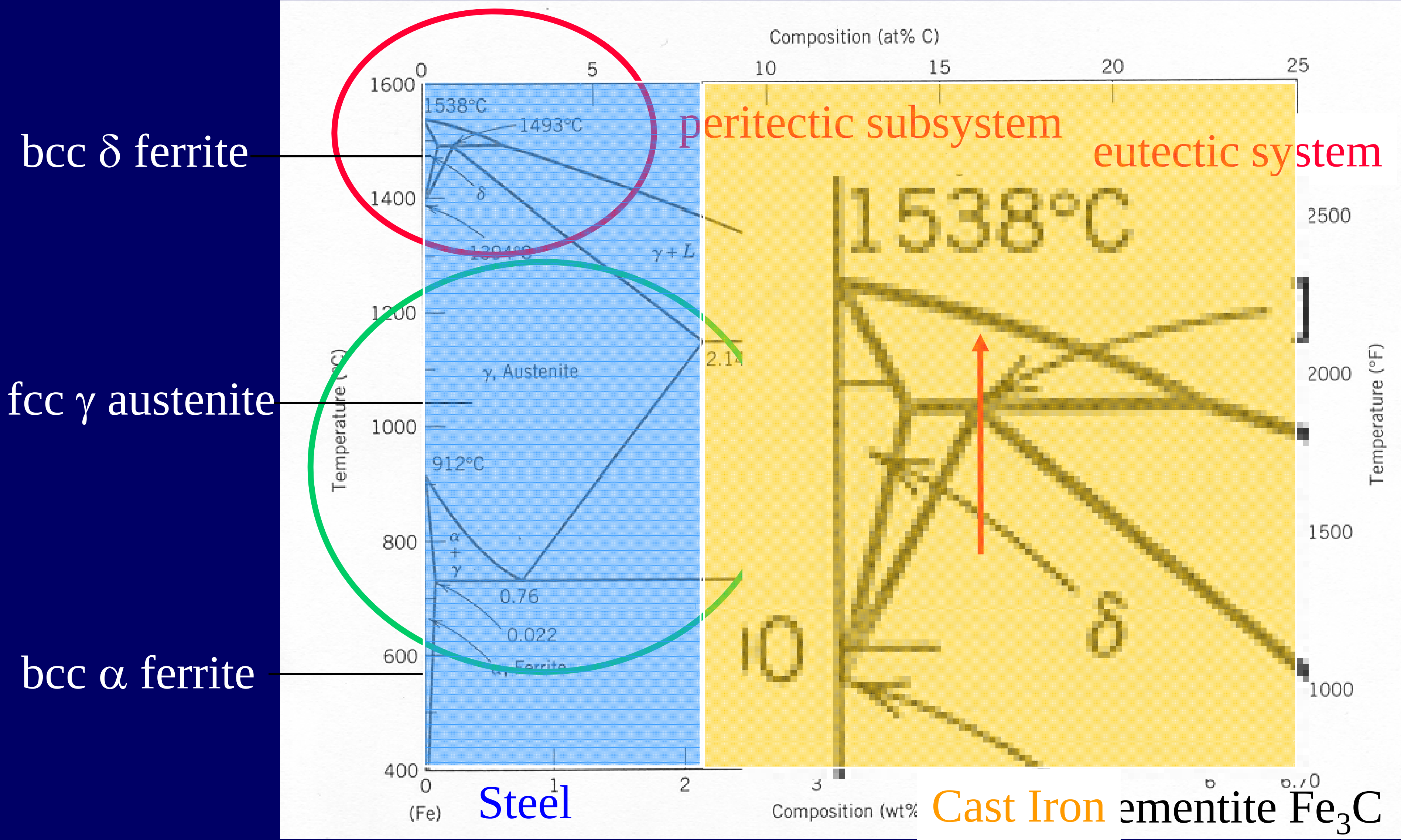
Structural Materials



The Iron-Carbon Phase Diagram

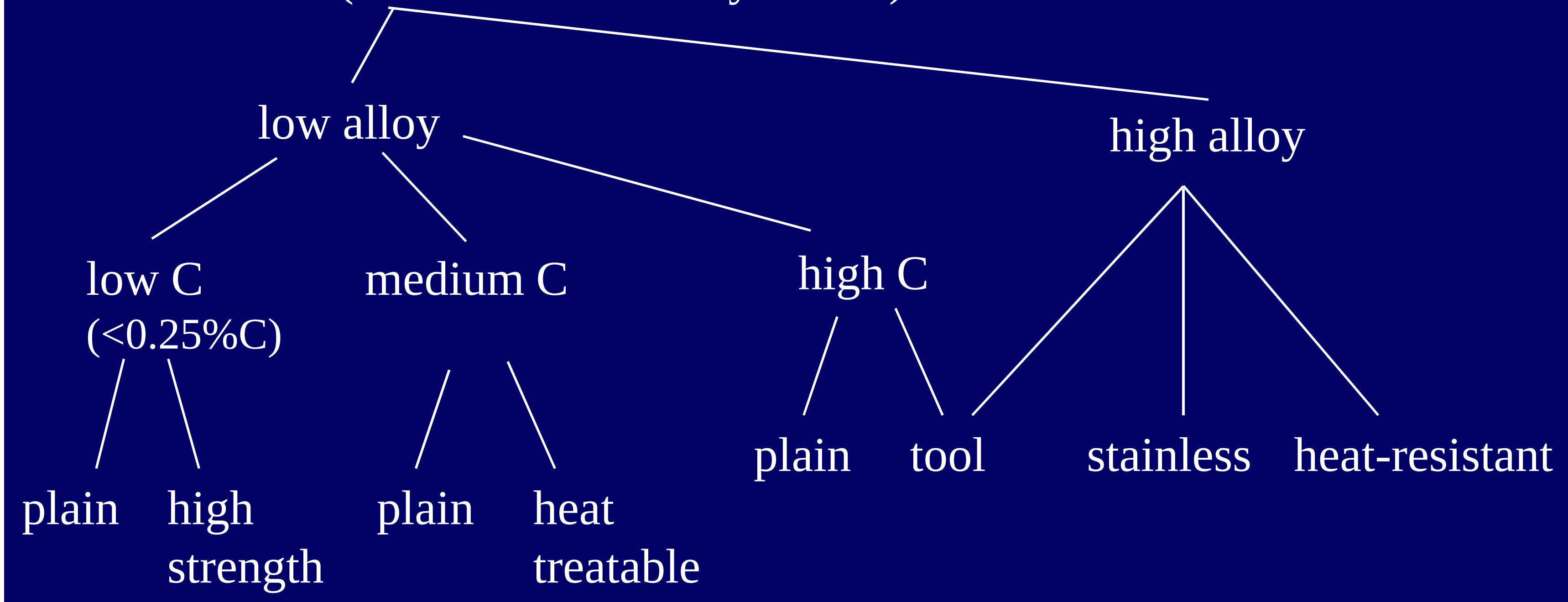


Ferrous Alloys

=> economical production process (natural resources, extraction, alloying, fabrication)
=> extremely versatile – wide range of physical/mechanical properties possible

Steels
(< 2%C – technically <1%C)

Cast Irons
(> 2%C – technically 2.5-4%C)



Low-Carbon Steels

plain
greatest quantity
c_C<0.25% ferritic-pearlitic, $\sigma_Y \approx 275$MPa
strengthening only by cold work
ductile=> machinable, weldable,
inexpensive

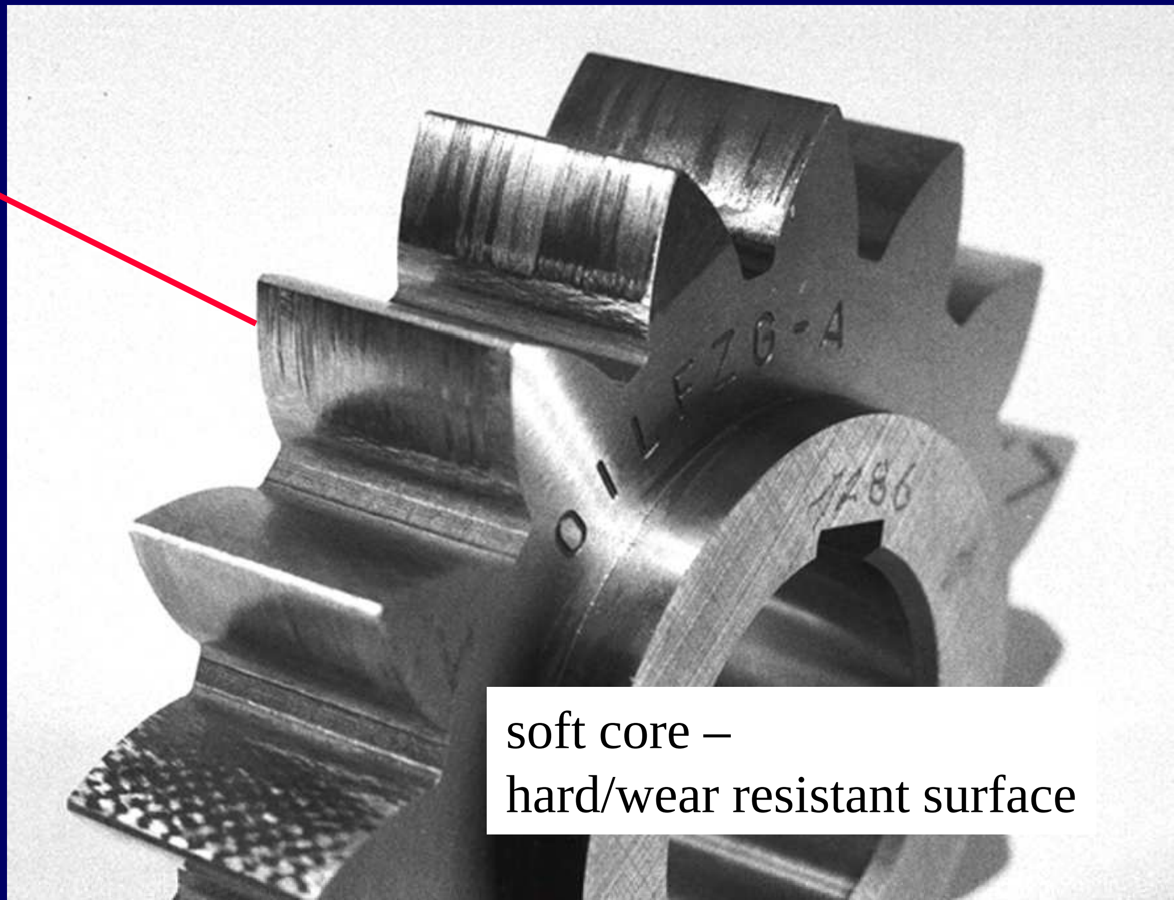
applications:
automobile bodies
structural shapes
(e.g. construction beams)

high-strength low-alloy
$c_{\text{alloying elements}}$<10%, $\sigma_Y \approx 480$MPa
more critical structures
(bolted, low temperatures...)

Medium (High) Carbon Steels

c_C=0.25...0.6% (, suitable for heat treatment hardening, $\sigma_Y \approx$400-2000MPa

strengthening by
-austenitizing (normalizing)
-quenching (often surface)
-tempering
(by addition of Cr, Ni, Mo)



applications:
railway wheels, gears..
high C steels:
cutting tools, springs, wire..

High-Alloy Steels

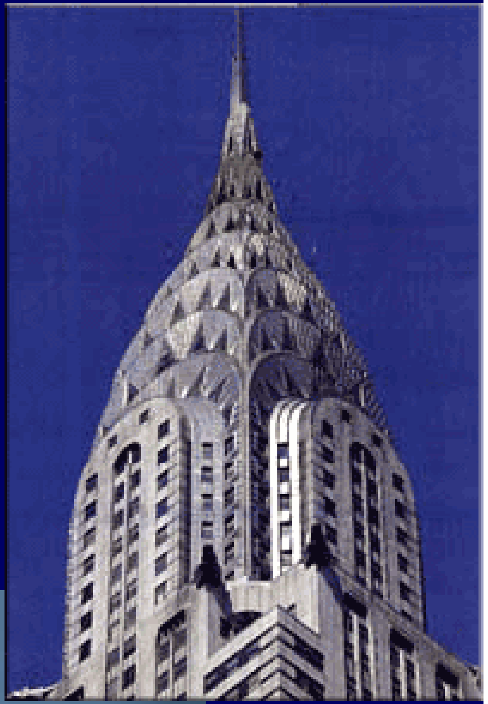
c_{Cr}>11% => corrosion resistant

1 martensitic
cutlery (surgery knifes)...

2 austenitic (γ fcc at RT by adding Ni
chemical, food processing
construction...

3 ferritic
(very) high temperatures (Cr up to 25%), automotive exhaust
systems catalytic converter...

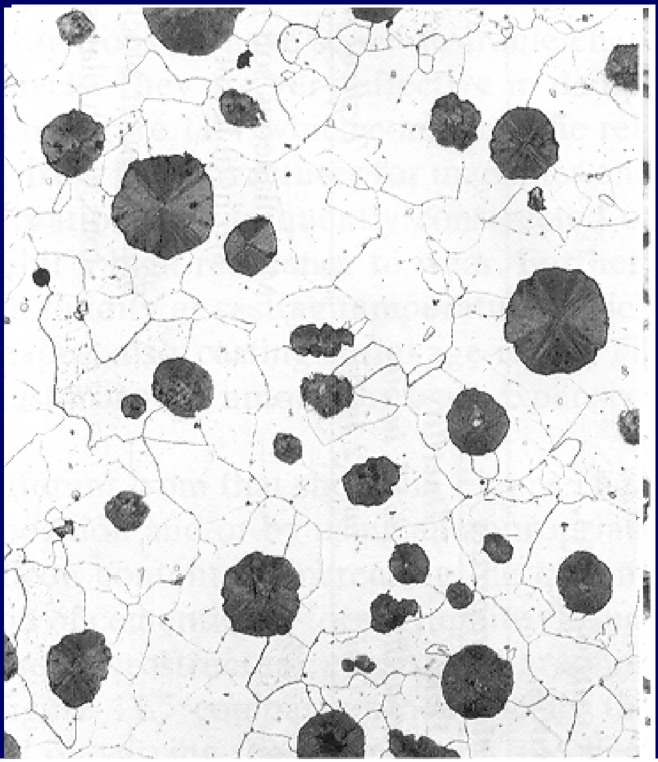
2-3 strengthening only by cold work
or precipitation hardening

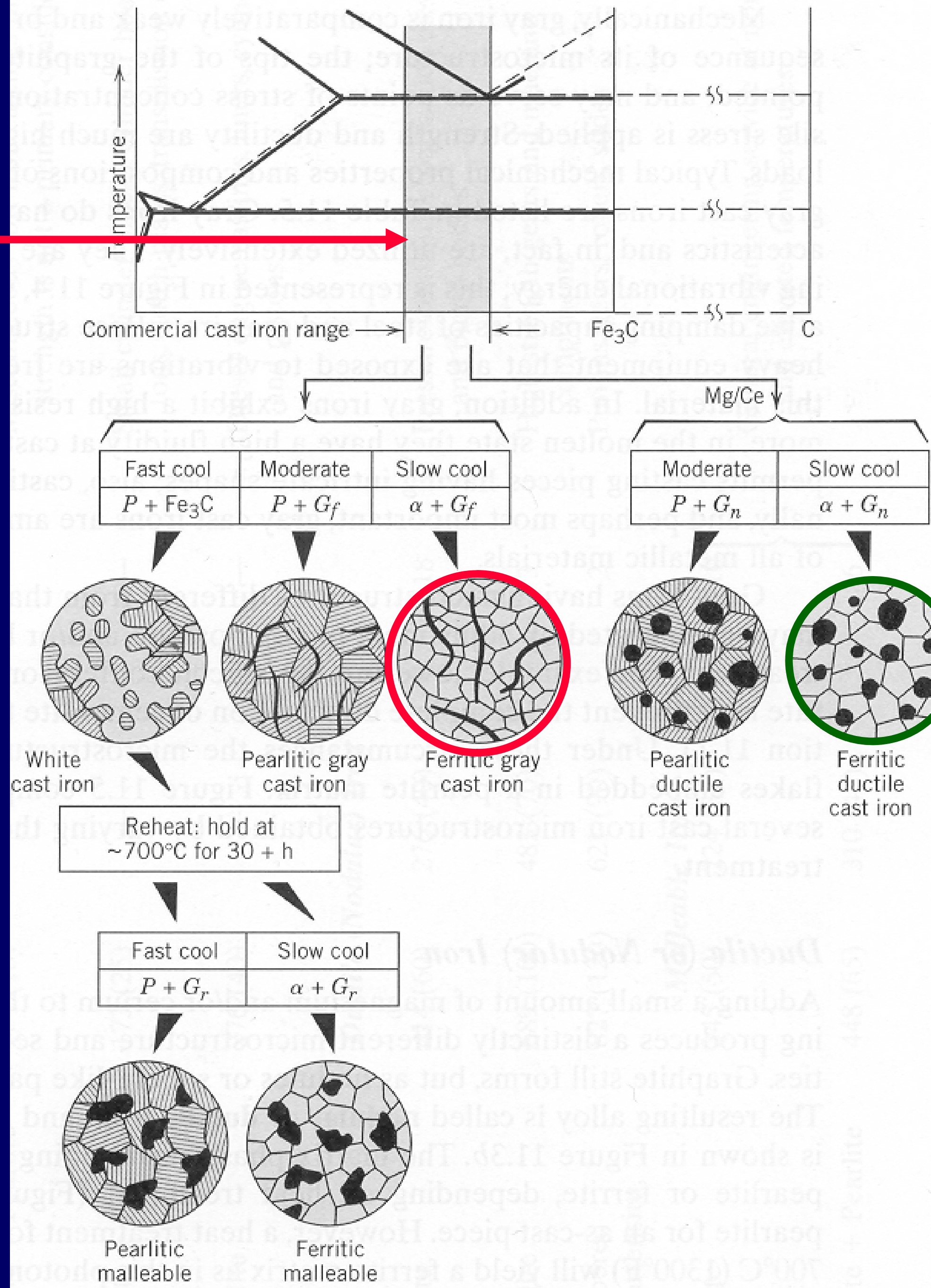


Cast Irons

c_C>2.14%, typical 3...4.5%
low liquidus betw. 1150...1300°C
=> fluidity at casting temperature
stable Fe – C system!!

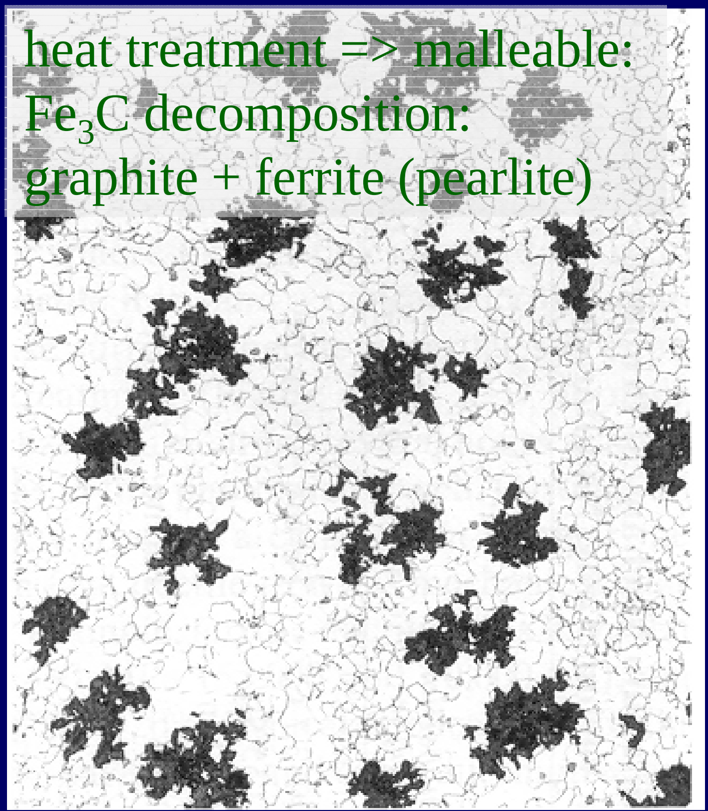
+ Mg, Ce (slow cool):
ferrite + graphite nodules

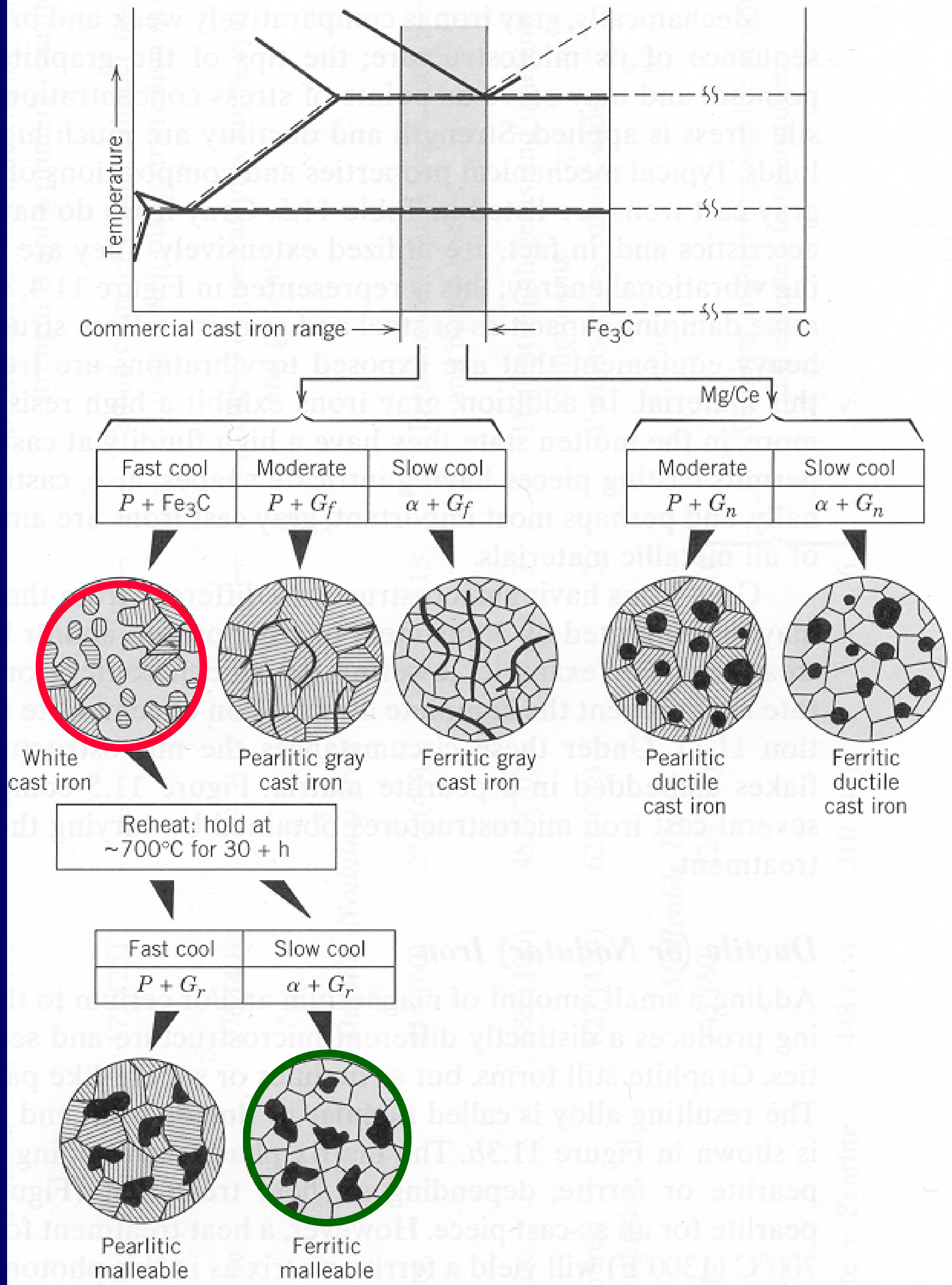




Cast Irons

fast cool:
white cast iron
cementite + pearlite
brittle/hard





Non-Ferrous Alloys

disadvantages steel:
-high density (7.85g/cm^3)
-low conductivity
-poor corrosion resistance (low-alloy steels)
-lack of " special" properties

→ Al alloys (1/3 density, corrosion resistant, conductive)

Mg alloys (lowest density)

Ti alloys (low density, high strength, corrosion resistance)

Ni alloys (corrosion resistance also at high temperatures)

Cu alloys (conductive, corrosion resistance)

refractory metals (Nb, Mo, W, Ta – very high T_m (W: 3410°C)

noble metals (Au, Pd, Pt..functional materials: catalysts)

others (Pb, Zn, Sn, functional materials, corrosion protection)

Aluminum Alloys

low density (2.7g/cm³) fcc
T_m=660°C (technical limit!!), E=70GPa

corrosion resistant/conductive/formable
heat-tretable: e.g. $MgZn_2$ particles
but limited weldability

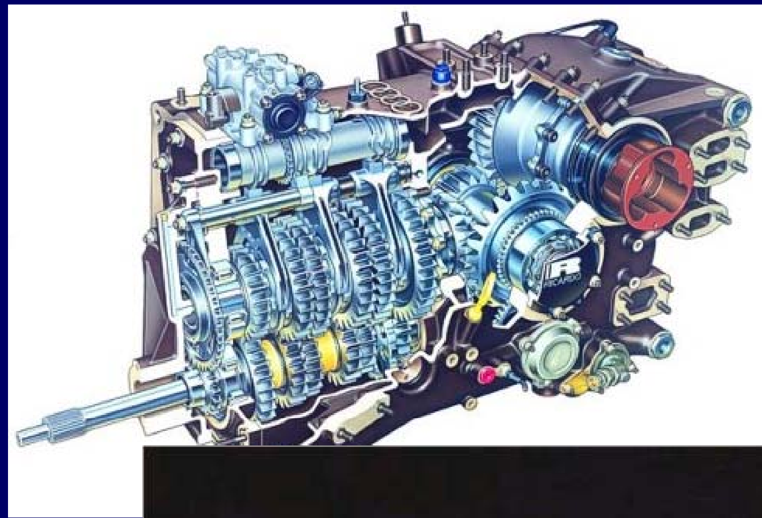
applications:
automotive bodies/aircraft structures/
furniture/wheels etc.

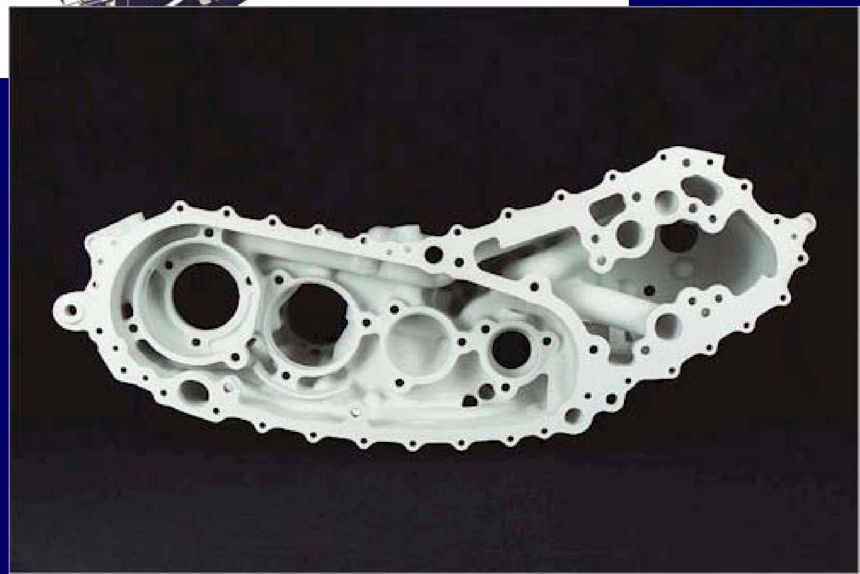
Magnesium Alloys

very low density (1.7g/cm³) hcp
T_m=651°C, E=45GPa

susceptible to corrosion
mostly cast
(e.g. AZ91, Mg-Li alloys)

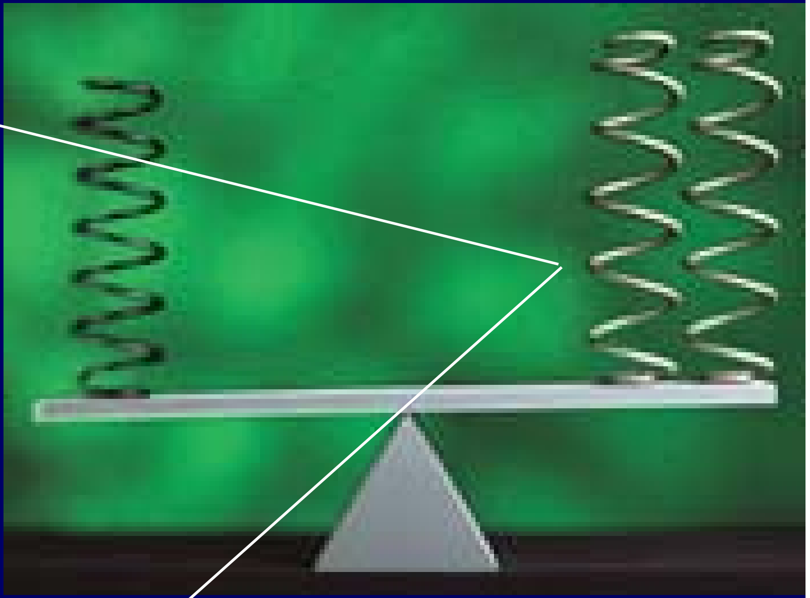
applications:
e.g. gear boxes, steering wheels, hand-held devices





Titanium Alloys

low density (4.5g/cm³) *a* hcp above 880°C β bcc
T_m=1670°C, E=107GPa



corrosion resistant (up to approx. 600°C)/
biocompatible
heat treatable -> αβ-two phase microstructure

applications:
α+β Ti-6Al-4V: implants, structural airframe components
near α Ti-8Al-1Mo: compressor disks
β Ti-10V-2Fe-3Al: high strength applications: e.g. springs, landing gear, rotor heads

Copper Alloys

high density (8.2g/cm^3) fcc
T_m=1083°C, E=130GPa

corrosion resistant, conductive
heat-treatable (high strength CuBe alloys, 1...2.5% Be)
brass (e.g. Cu-37%Zn)
bronze (e.g. Cu-30%Ni)

applications:
e.g. water pipes, roofs, electric/electronic devices/nuts/ propellers...

Nickel-Alloys - Superalloys

high density (8.9g/cm³) fcc
T_m=1453°C, E=210GPa

corrosion resistant (up to very high temperatures)/
alloyable
based on Ni-20Cr-5Al: superalloys:
precipitation strengthened (γ-Ni_3Al)
creep resistant
(also: Fe-based and Co-based superalloys)

applications:
petrochemical industry, heating elements,
energy production – gas turbines

Metal Fabrication

Forming Operations

forging	rolling
extrusion	drawing

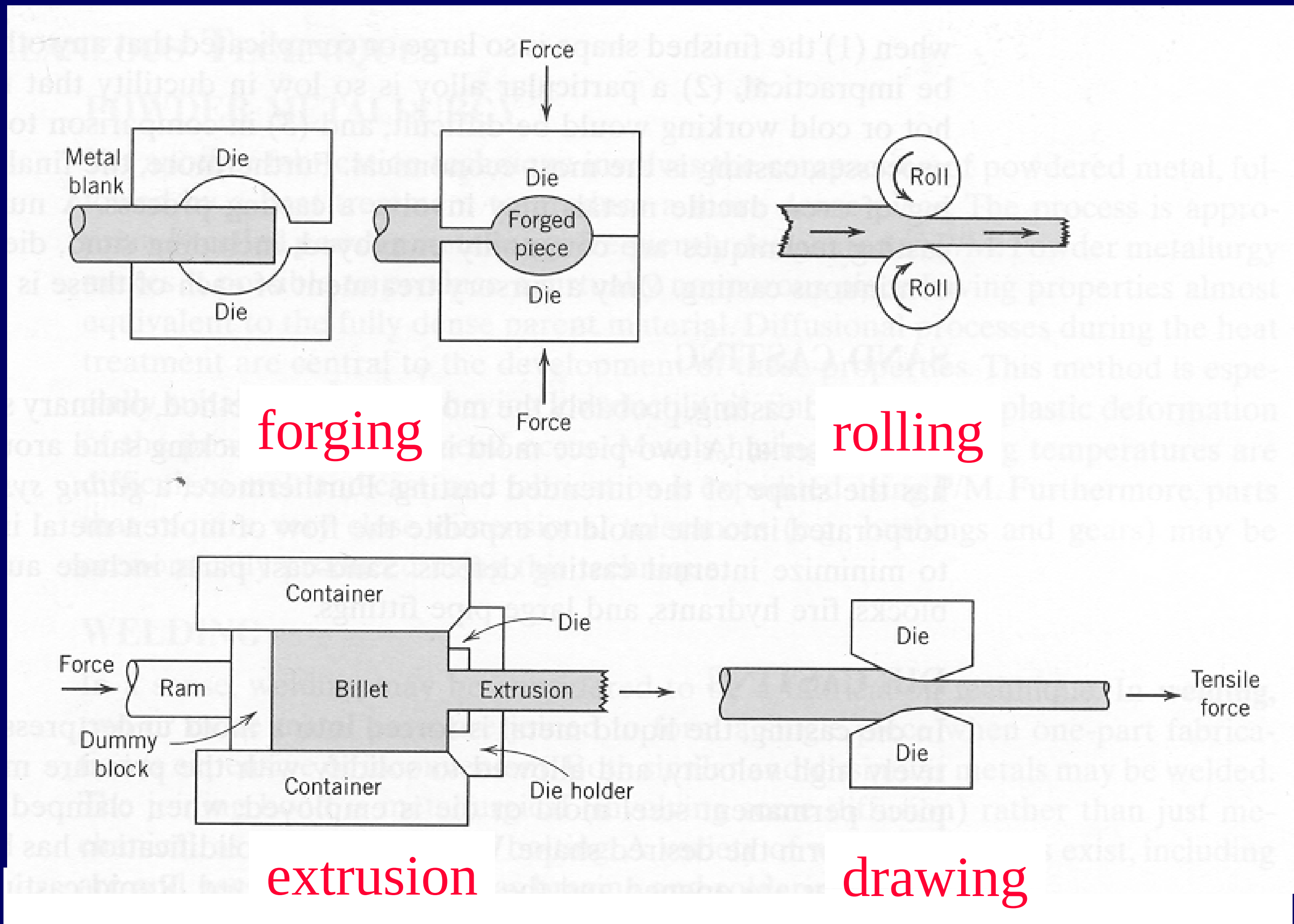
Casting

sand	die
investment	continuous

Miscellaneous

powder metallurgy	welding

Metal forming



→ heat treatment: normalizing, hardening, recrystallization..

Heat treatment

Annealing

Process annealing
Stress relief

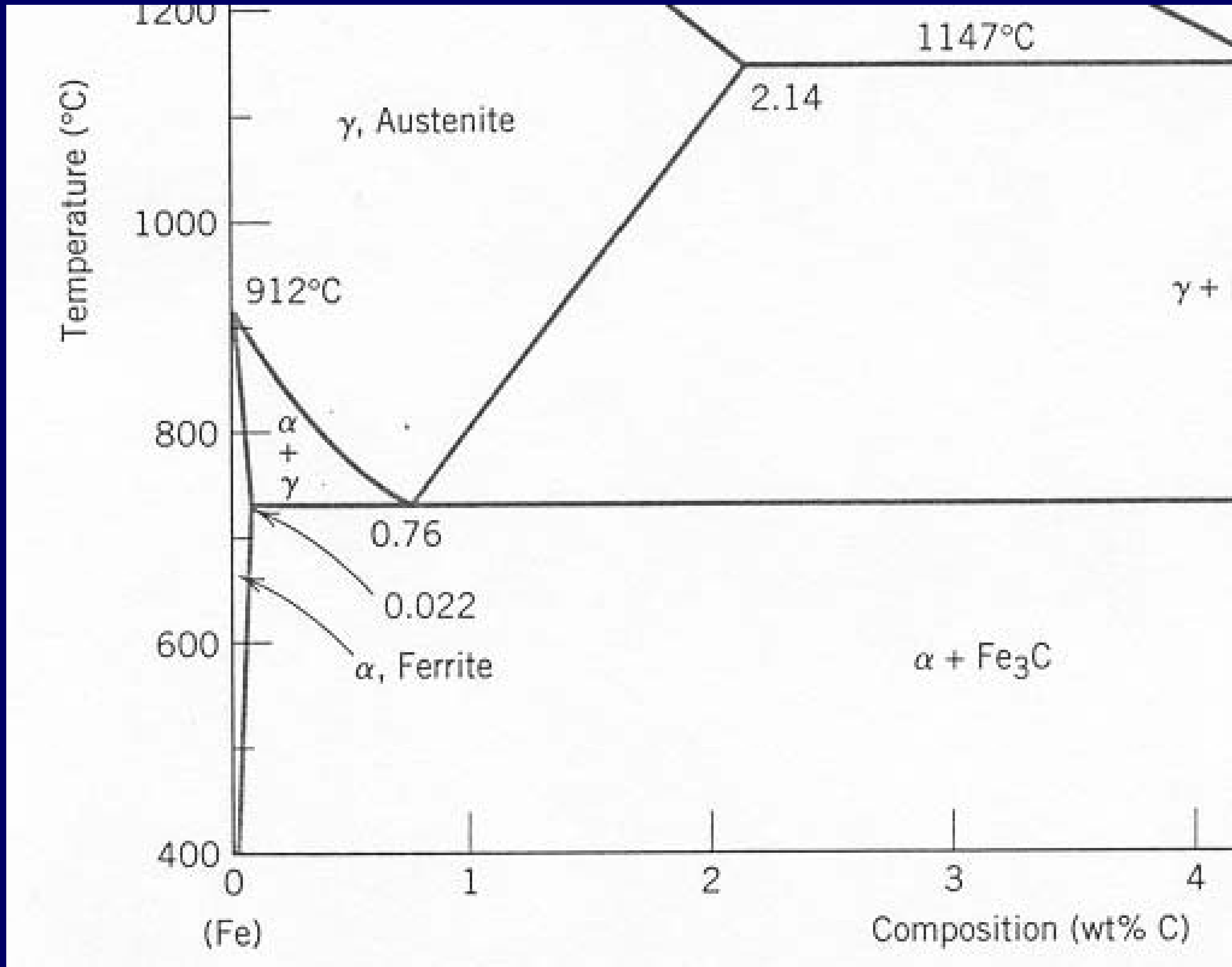
Annealing of ferrous alloys

normalizing
Full anneal
Spheroidizing

Hardenability

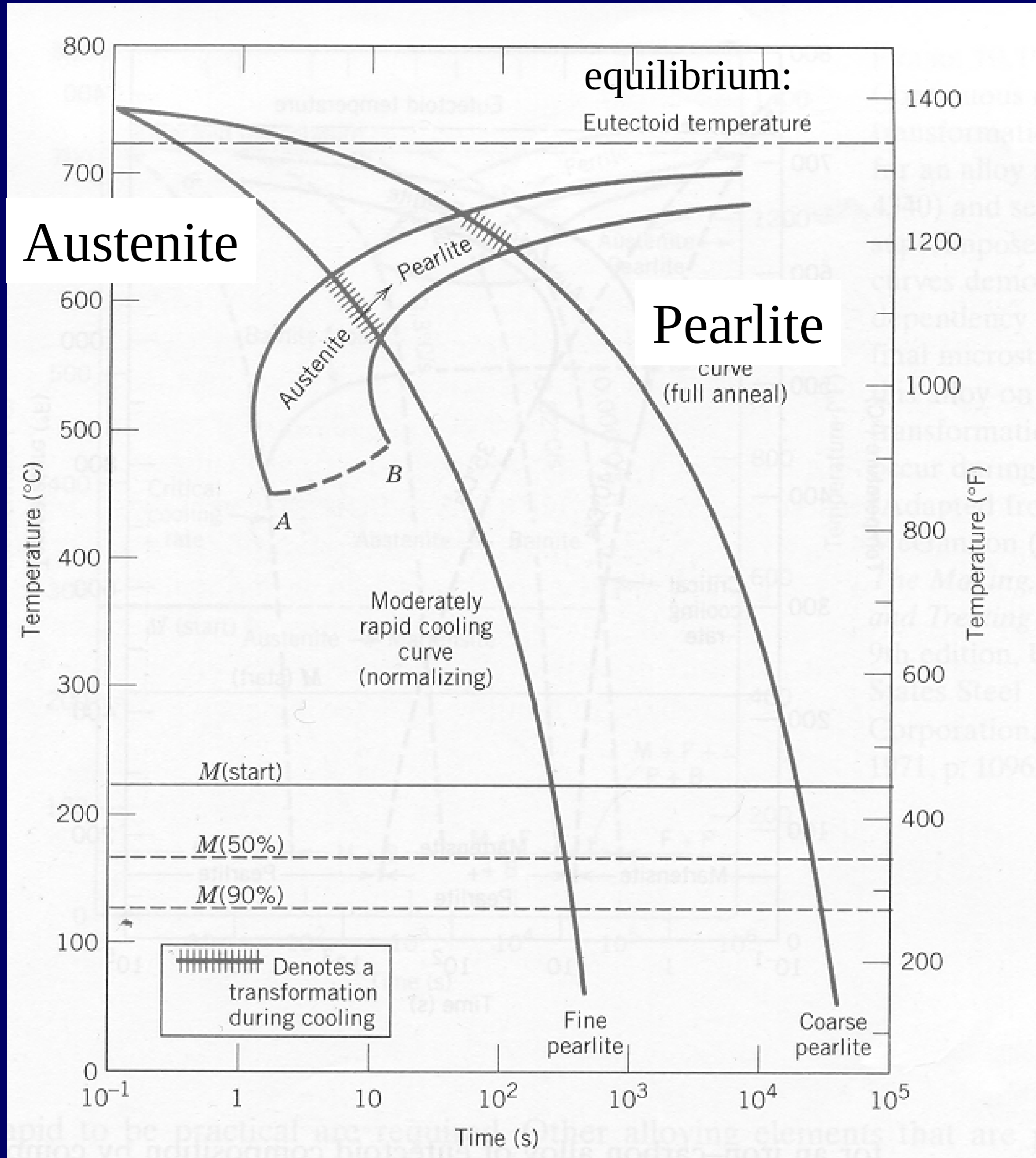
The Jominy End-Quench Test

Reminder: Iron-Carbon Phase Diagram

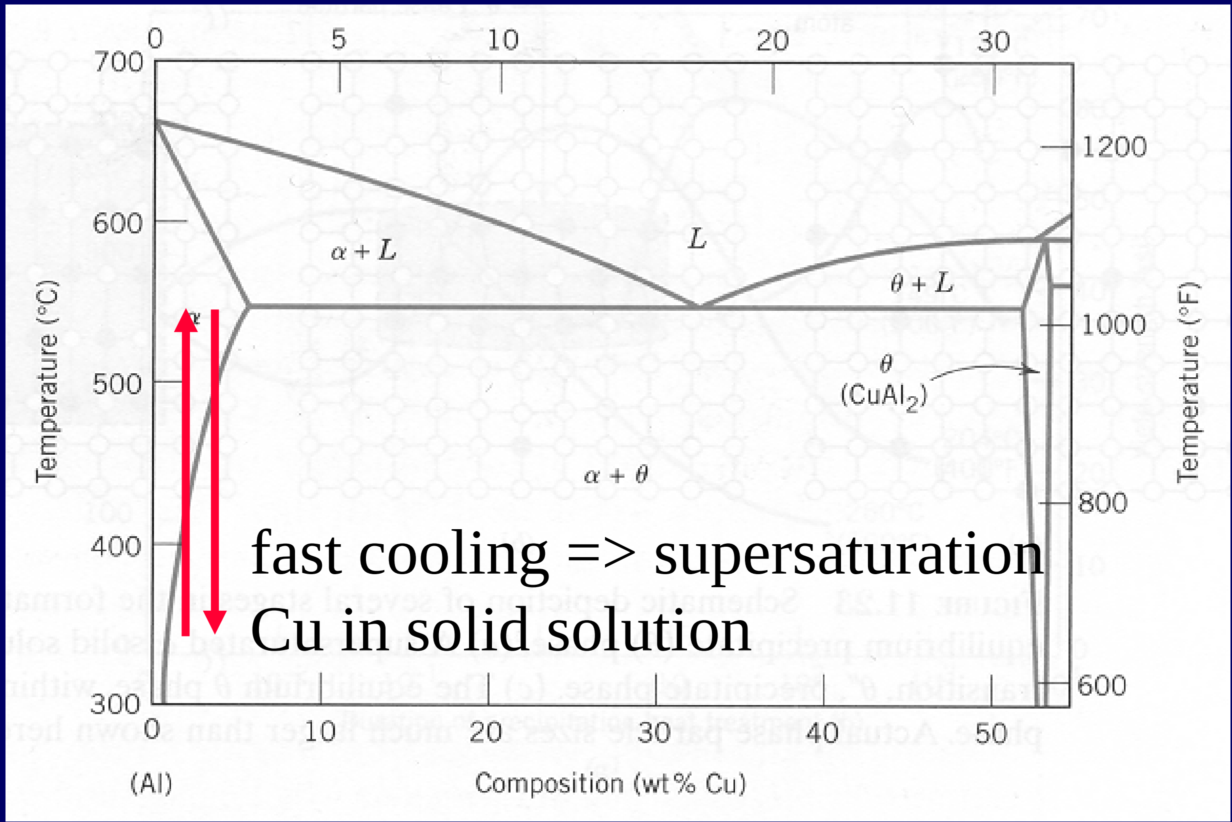


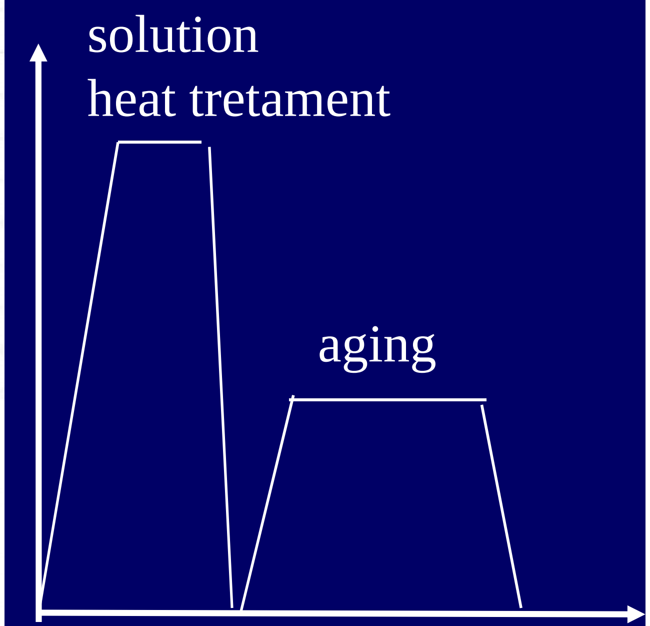
Alteration in Microstructure

continuous cooling transformation (CCT)



Precipitation Heat Treatment



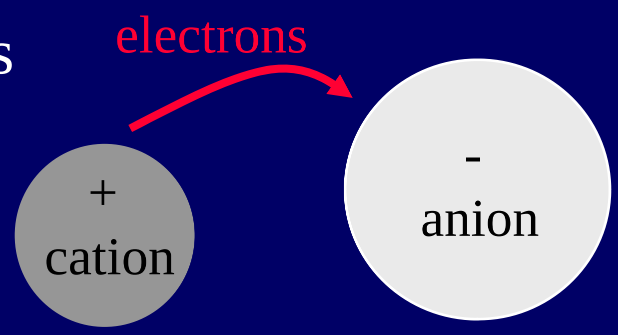


Ceramics

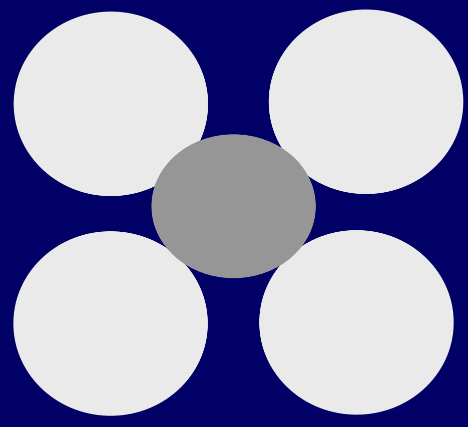
Ceramics

inorganic – non-metallic materials
- china/dishes
- cemente/concrete
- functional ceramics
- structural ceramics

ionic – covalent bonding of at least 2 atoms
(e.g. Al_2O_3: 63% ionic, SiC: 12% ionic)



structures depending on a) electrical charge
b) atomic radii (r_C/r_A)



stable – cations are in contact with surrounded anion

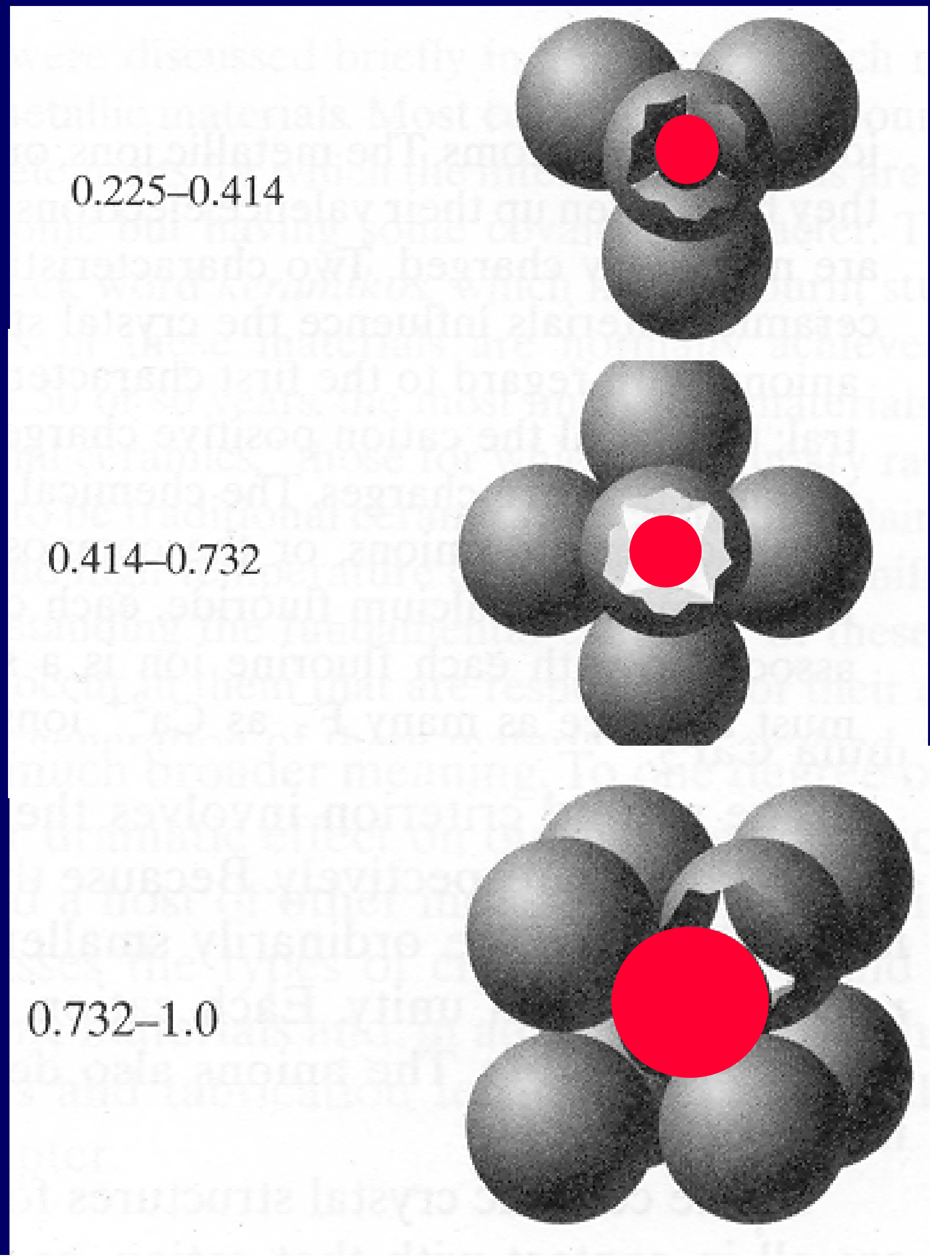
Structure of Ceramics

coordination number 4 r_C/r_{A}:

coordination number 6 r_C/r_{A}:

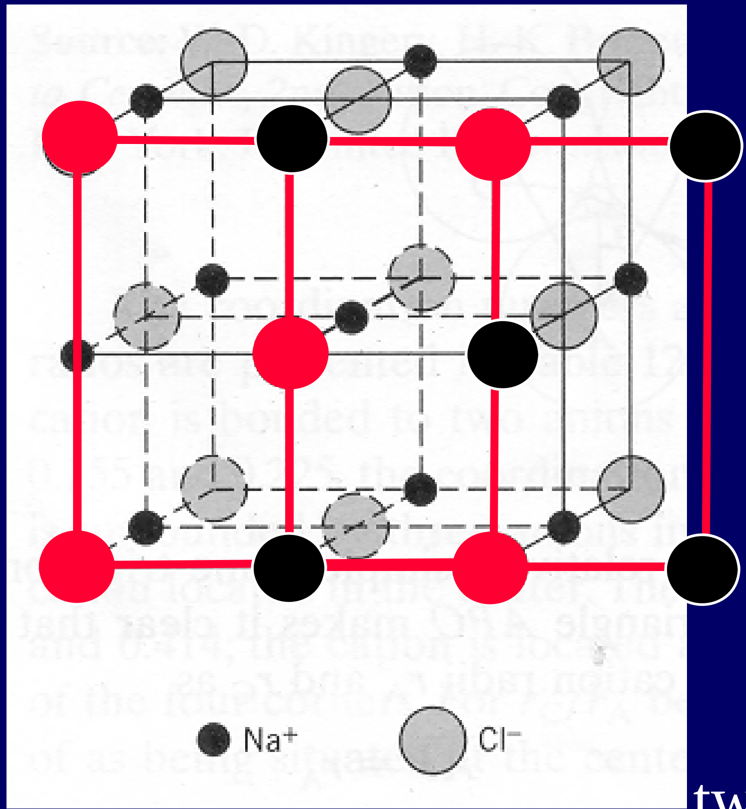
e.g.: Al_2O_3:
Al^{3+}: r_C=0.053nm, O^{2-}: r_A=0.140nm

coordination number 8 r_C/r_{A}:



AX Structures

e.g. NaCl



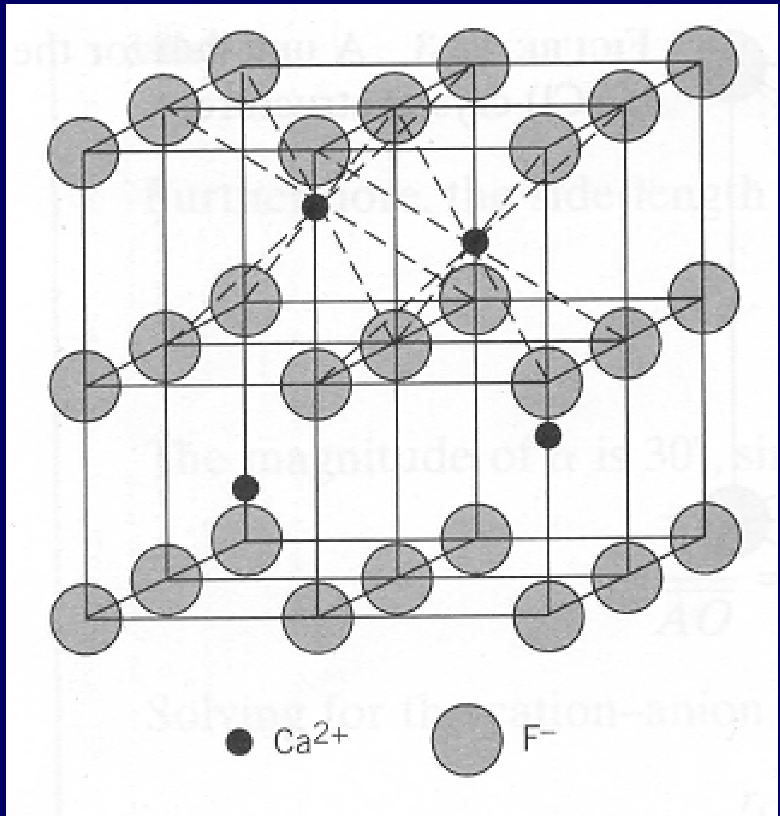
fcc anionic (Cl^-) lattice

fcc cationic (Na^+) lattice

two interpenetrating fcc lattices:
e.g. MgO, MnS, FeO
(coordination number 6)

A_mX_p Structures

e.g. CaF_2
r_C/r_A=0.8
coord. 8



center cube positions only half-filled

(CsCl completely-filled)

$A_mB_nX_p$ Structures

e.g. $BaTiO_3$