PY2N20
Material Properties and Phase Diagrams
Lecture 6

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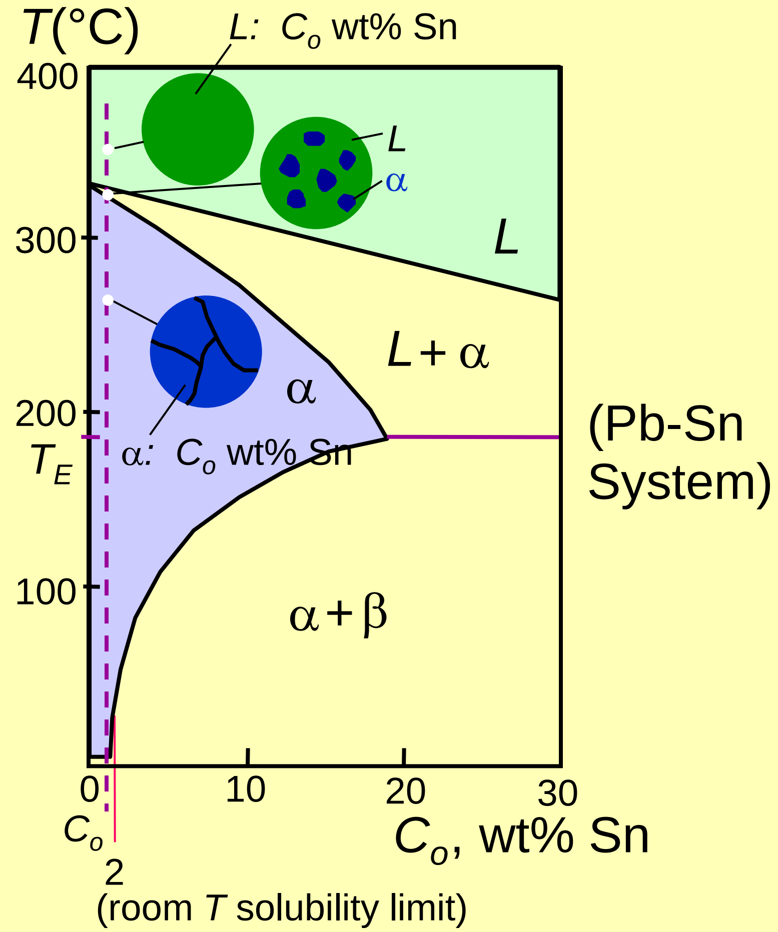
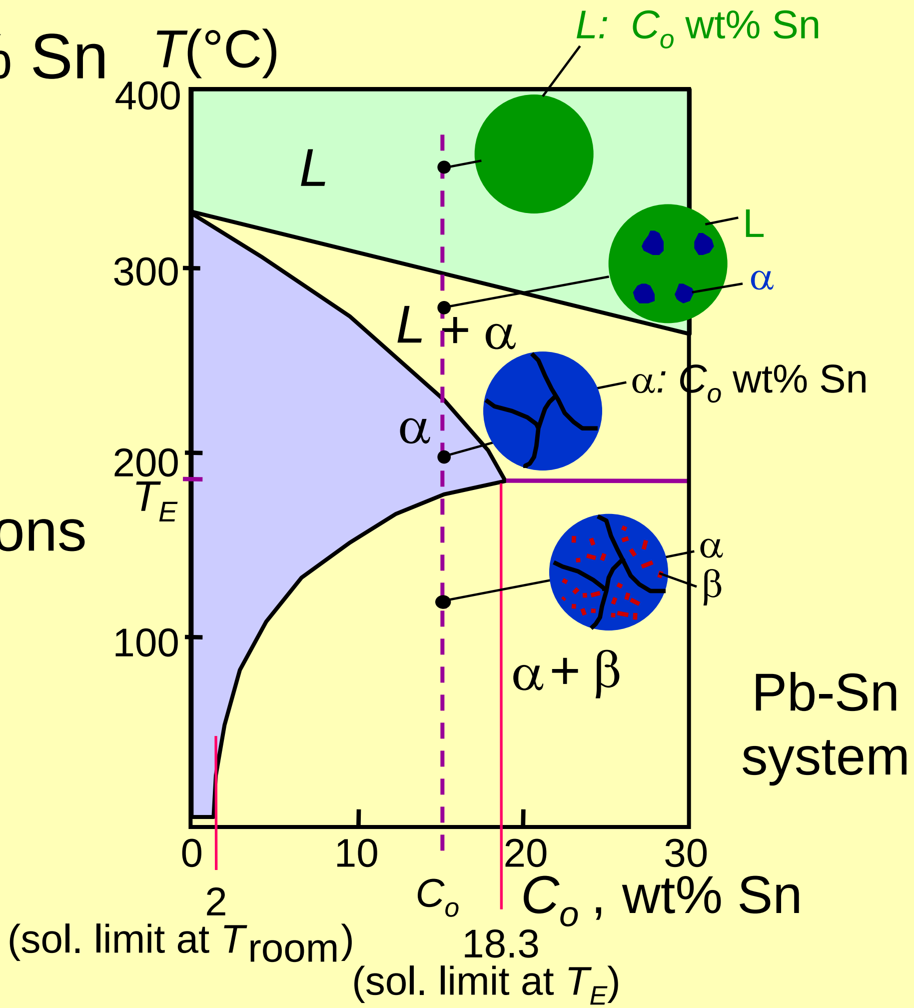
Microstructures in Eutectic Systems: I

- C_o < 2 wt% Sn
- Result:
  - at extreme ends
  - polycrystal of α grains
    i.e., only one solid phase.



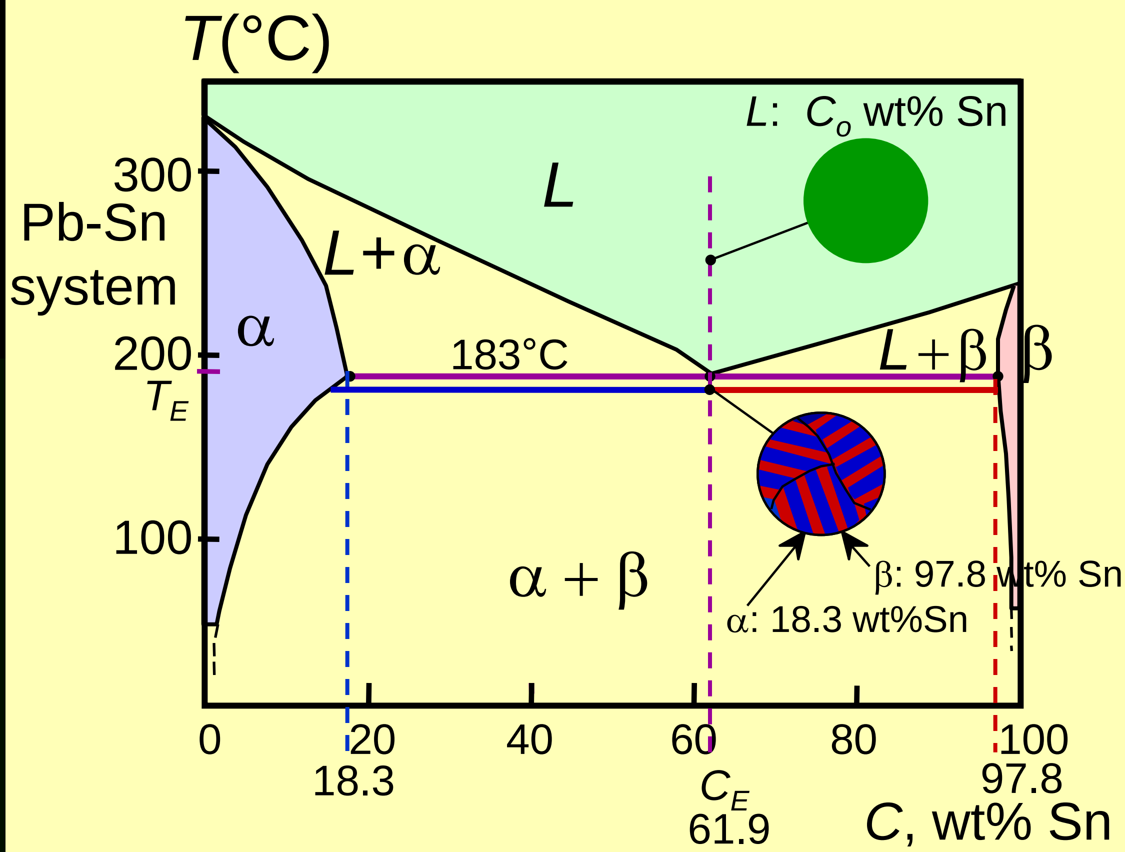
Microstructures in Eutectic Systems: II

- 2 wt% Sn < C_o < 18.3 wt% Sn
- Result:
  - Initially liquid + α
  - then α alone
  - finally two phases
    - α polycrystal
    - fine β-phase inclusions



Microstructures in Eutectic Systems: III

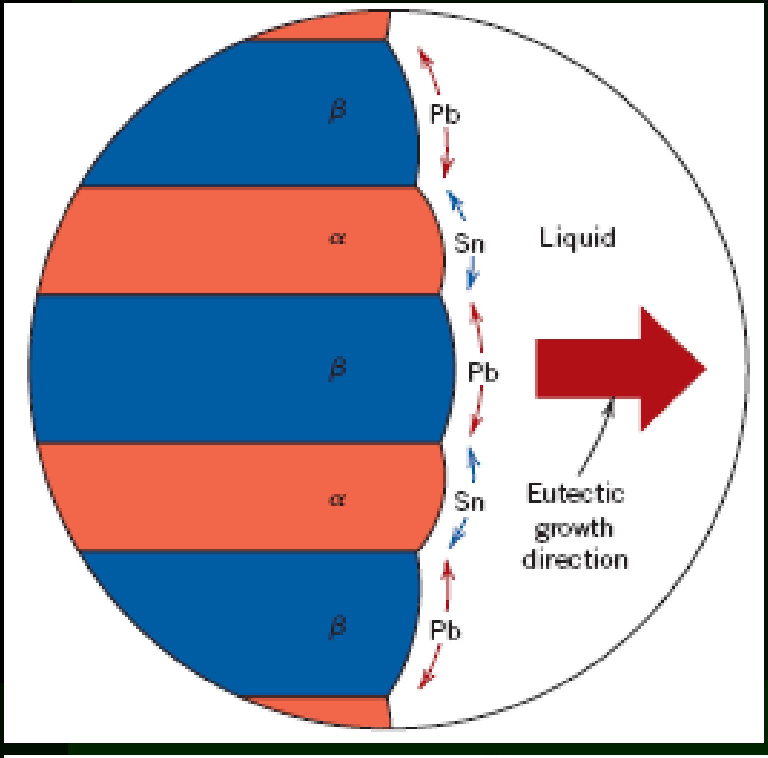
- $C_o = C_E$
- Result: Eutectic microstructure (lamellar structure)
  - alternating layers (lamellae) of α and β crystals.

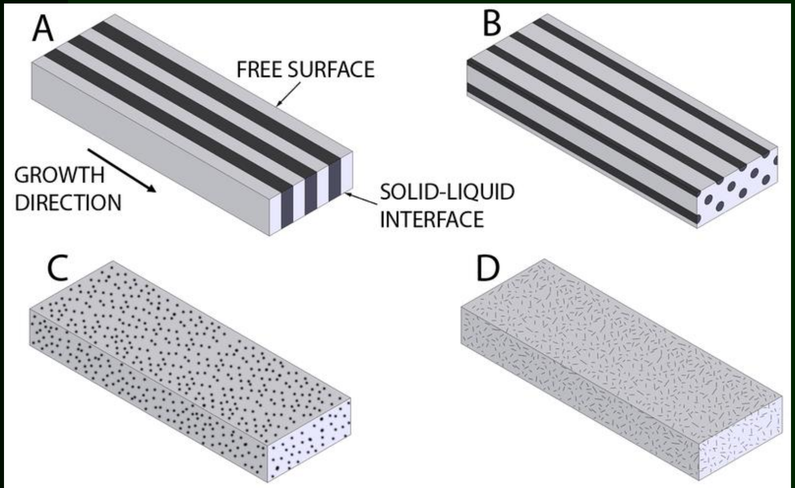


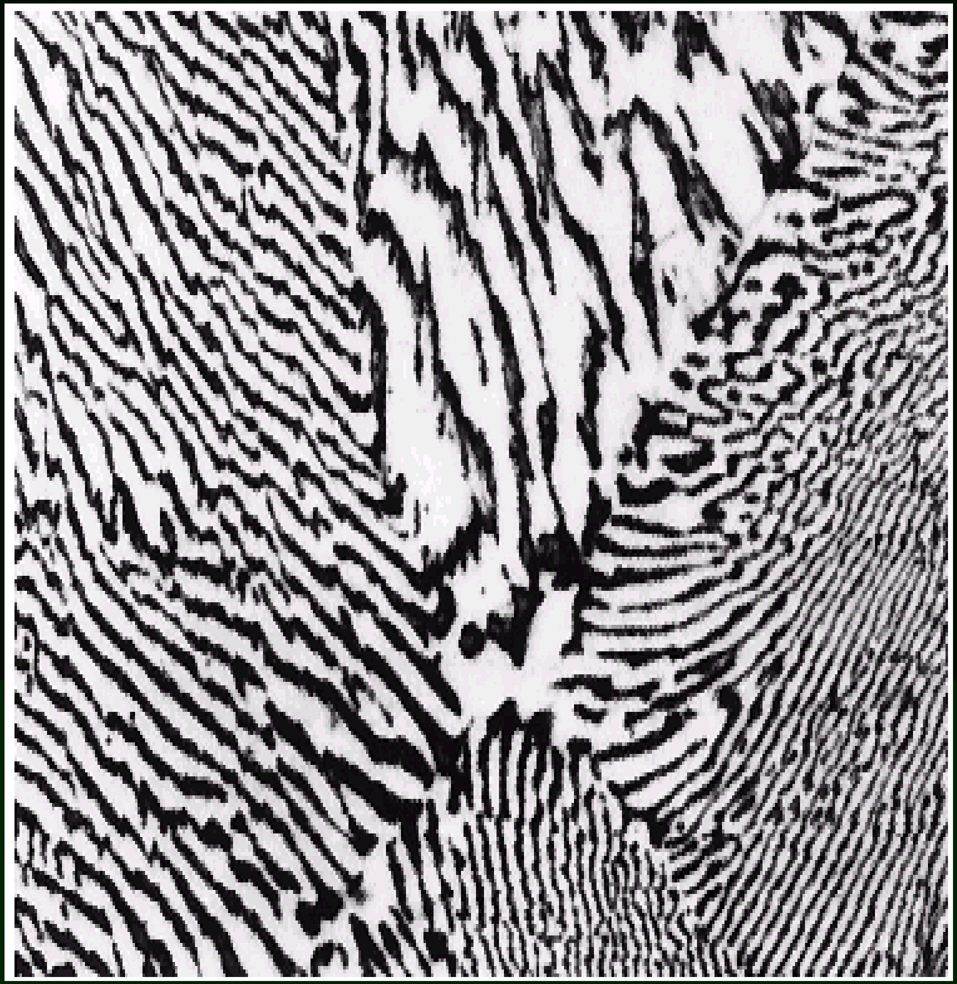
Micrograph of Pb-Sn eutectic microstructure

Adapted from Fig. 9.14, *Callister 7e.*

Lamellar Eutectic Structure



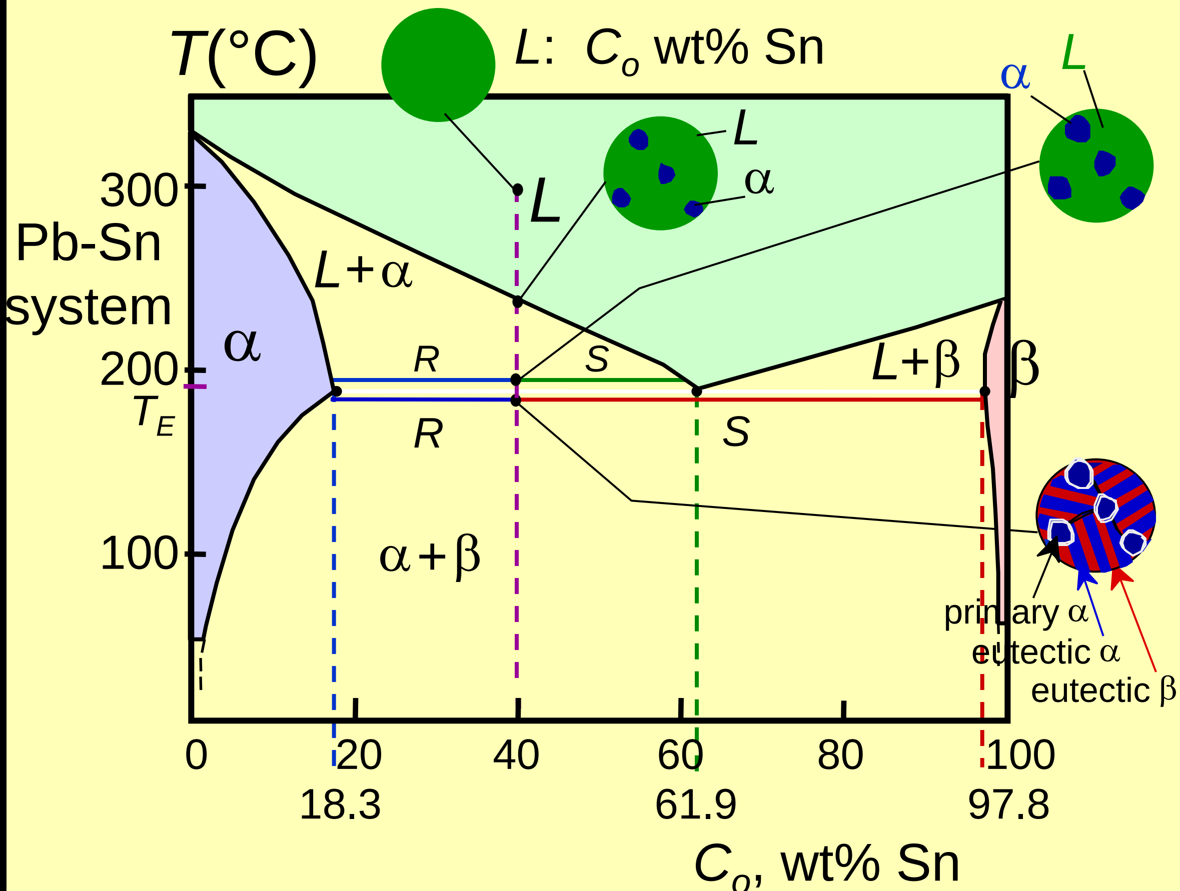




← Other possible eutectic structures are: rod-like, globular and acicular.

Microstructures in Eutectic Systems: IV

- 18.3 wt% Sn < C_o < 61.9 wt% Sn
- Result: α crystals and an eutectic microstructure



- Just above T_E:

C_α = 18.3 wt% Sn

C_L = 61.9 wt% Sn

$$W_\alpha = \frac{S}{R+S} = 50 \text{ wt\%}$$

$$W_L = (1 - W_\alpha) = 50 \text{ wt\%}$$

- Just below T_E:

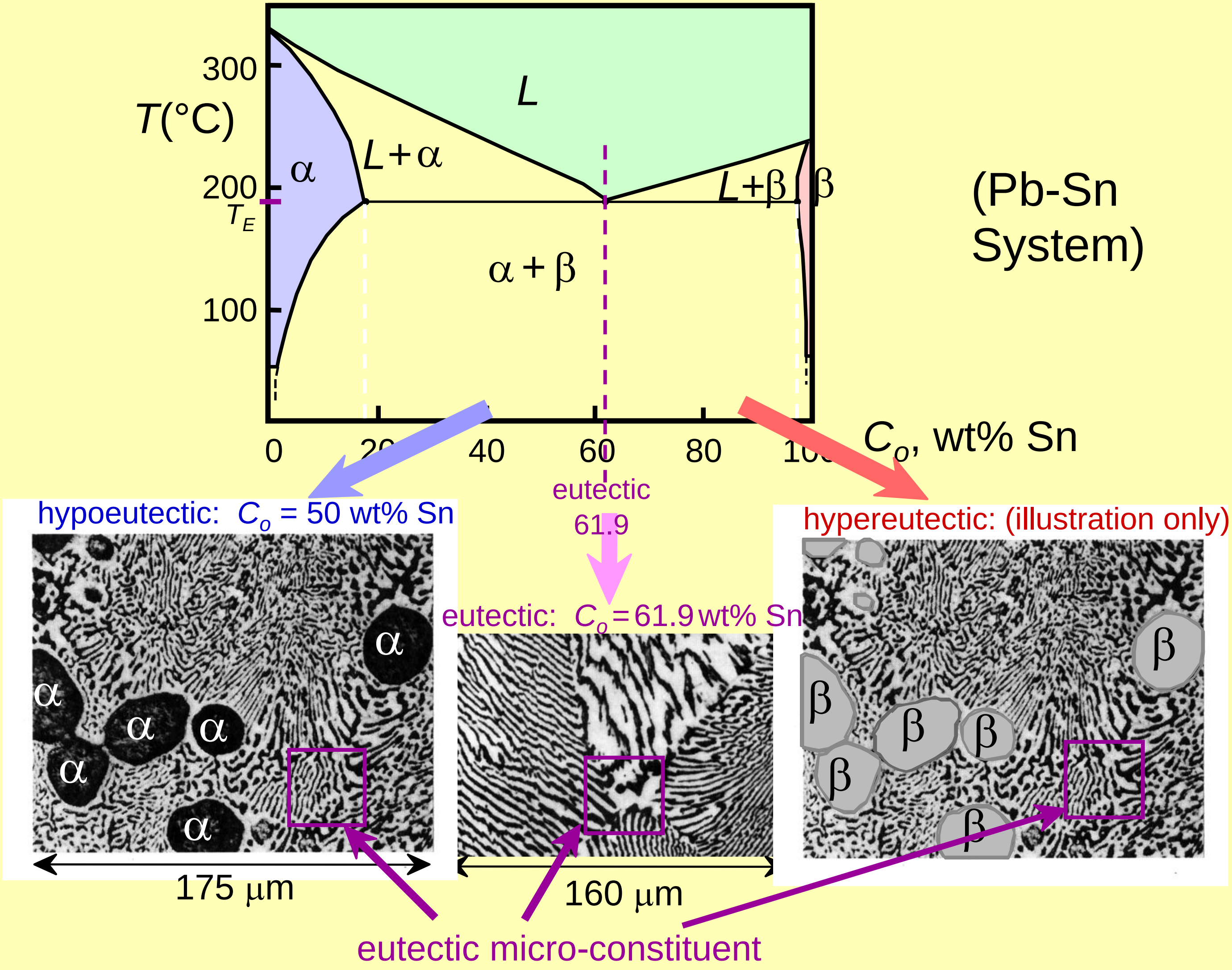
C_α = 18.3 wt% Sn

C_β = 97.8 wt% Sn

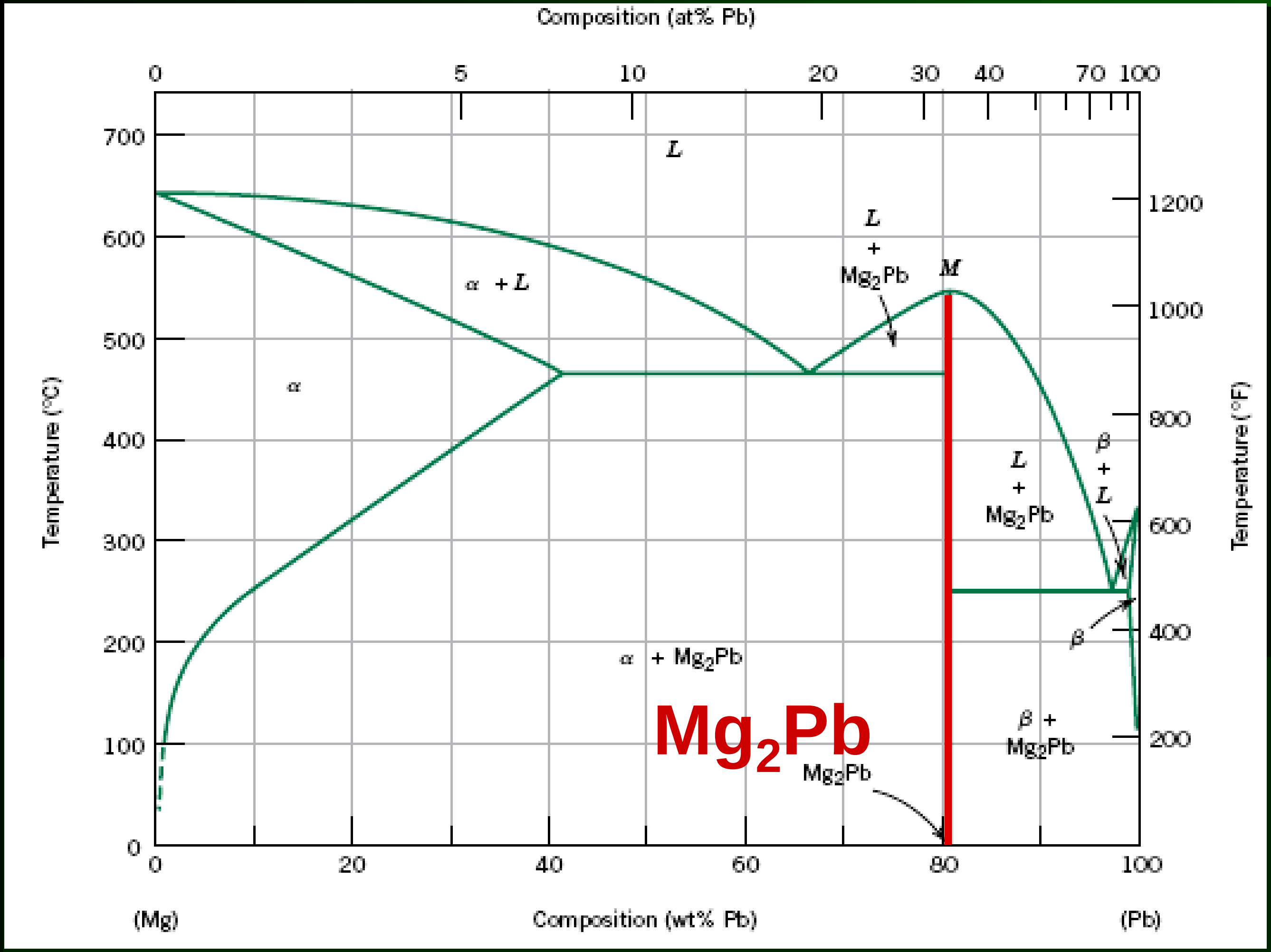
$$W_\alpha = \frac{S}{R+S} = 73 \text{ wt\%}$$

$$W_\beta = 27 \text{ wt\%}$$

Hypoeutectic & Hypereutectic



Intermetallic Compounds



Note: intermetallic compound forms a line - not an area - because the stoichiometry (i.e. composition) is exact.

Eutectic

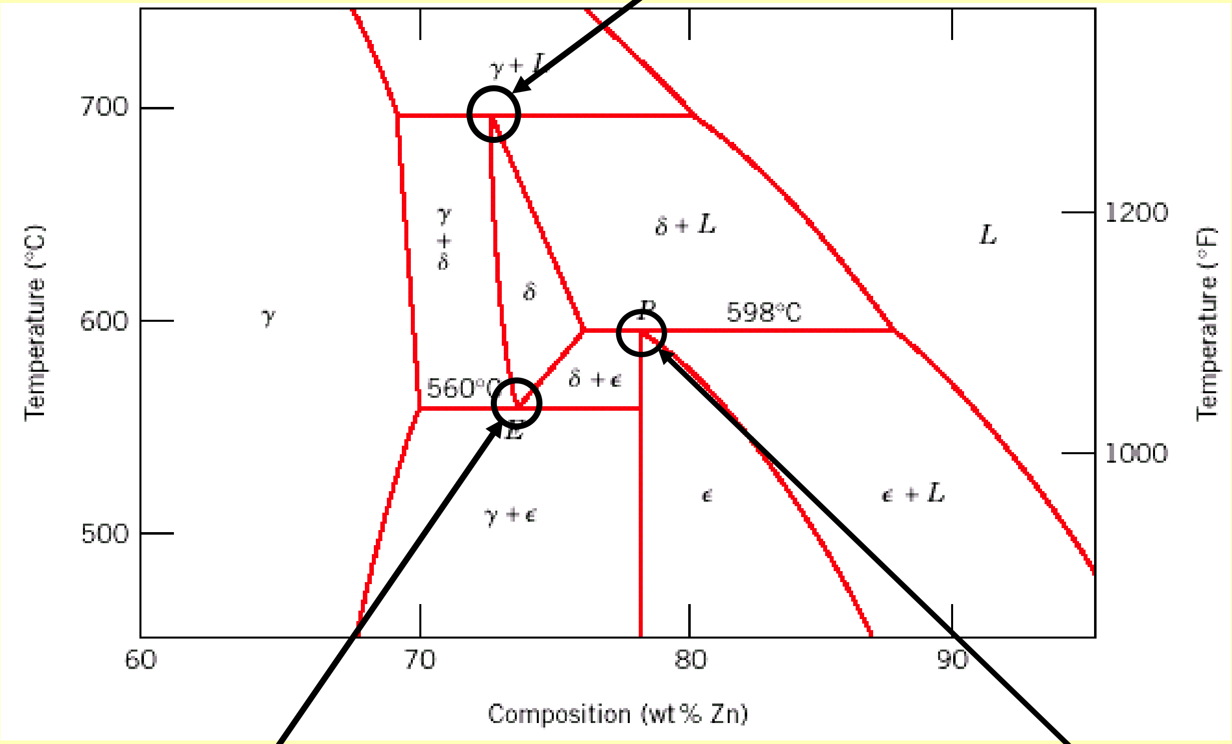
- **Eutectic - liquid in equilibrium with two solids**

$$L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + \beta$$

Example: Eutectoid & Peritectic

Peritectic transition $\gamma + L \rightleftharpoons \delta$

Cu-Zn Phase diagram



Eutectoid transition $\delta \rightleftharpoons \gamma + \varepsilon$

Peritectoid – solid state Peritectic

Eutectoid & Peritectic

- **Eutectoid - solid phase in equilibrium with two solid phases**

$$S_2 \rightleftharpoons S_1 + S_3$$

intermetallic compound - cementite

$$\gamma \underset{heat}{\overset{cool}{\rightleftharpoons}} \alpha + Fe_3C \qquad (727^oC)$$

- **Peritectic - liquid + solid 1 → solid 2**

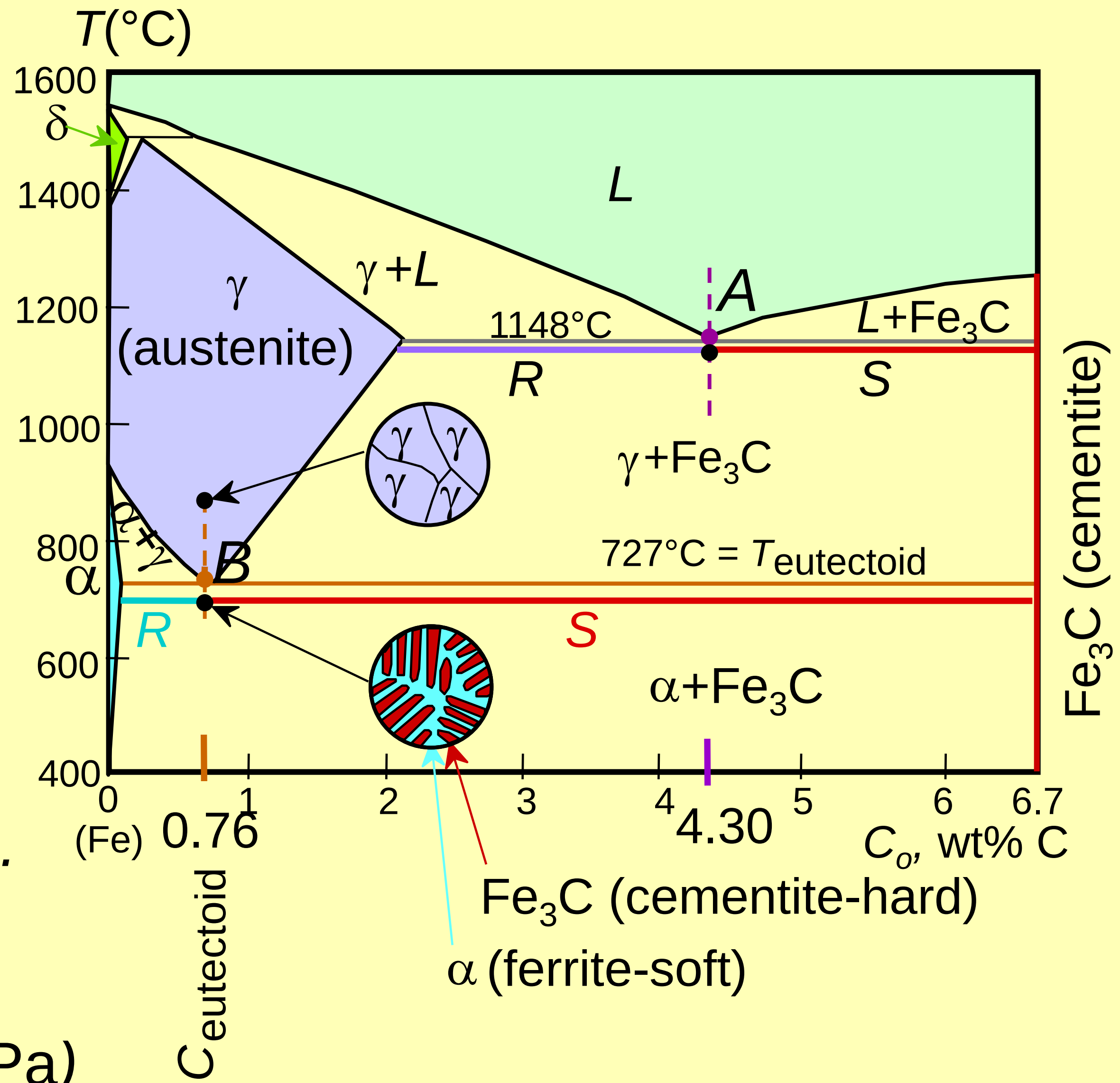
$$S_1 + L \rightleftharpoons S_2$$

$$\delta + L \underset{heat}{\overset{cool}{\rightleftharpoons}} \gamma \qquad (1493^oC)$$

περιτεκτικός → περι - included

Iron-Carbon Phase Diagram Extract

- 2 important points
  - -Eutectic (*A*): $L \Rightarrow \gamma + Fe_3C$
  - -Eutectoid (*B*): $\gamma \Rightarrow \alpha + Fe_3C$



α – bcc *(FM)*

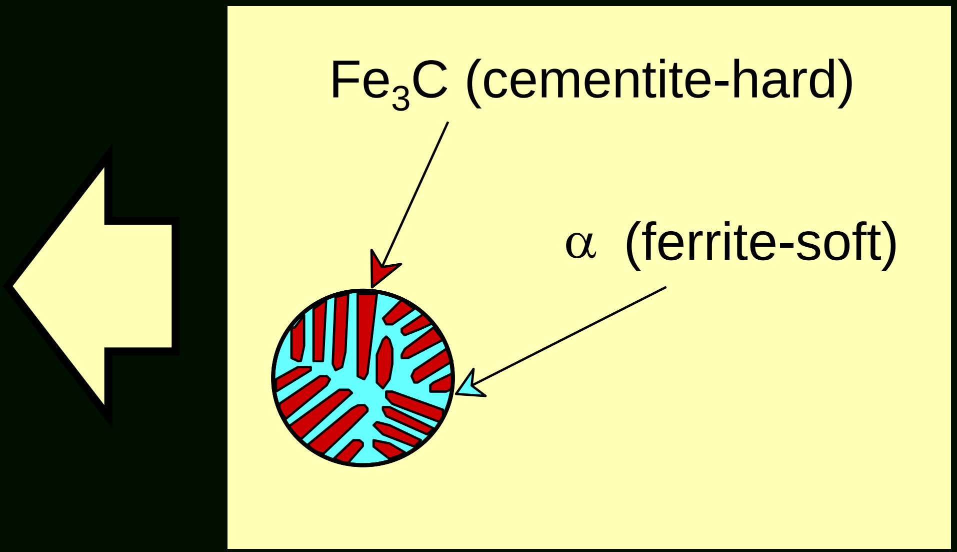
β – bcc *(NM) obs.*

γ – fcc *(NM)*

δ – bcc *(NM)*

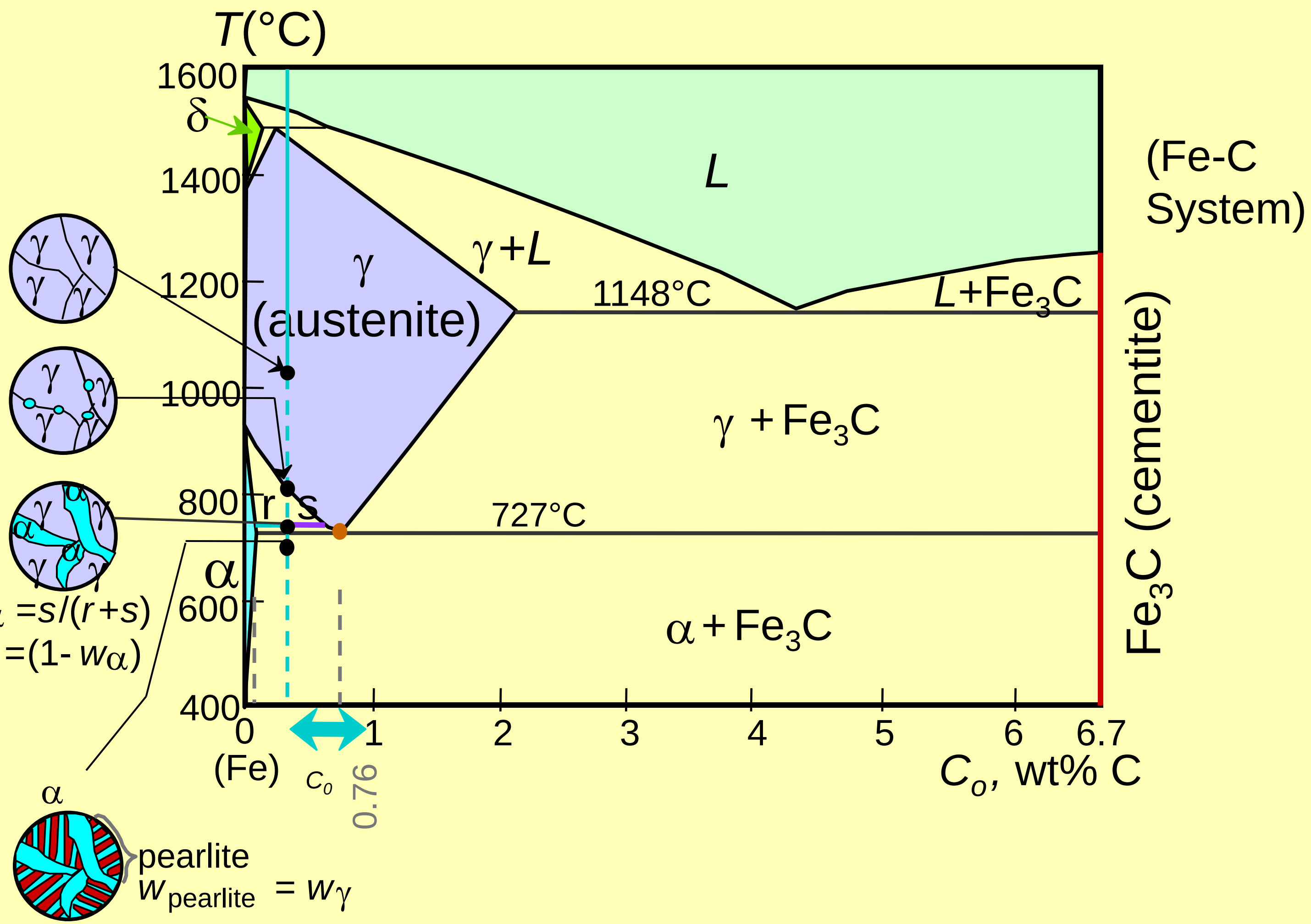
ε – *hcp (p* >13 GPa*)*

Pearlite



Result: Pearlite = alternating layers of α and Fe_3C phases

Hypoeutectoid Steel



$w_{\alpha} = s/(r+s)$

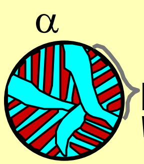
$w_{\gamma} = (1 - w_{\alpha})$

$w_{pearlite} = w_{\gamma}$

$w_{\alpha} = S/(R+S)$

$w_{Fe_3C} = (1 - w_{\alpha})$

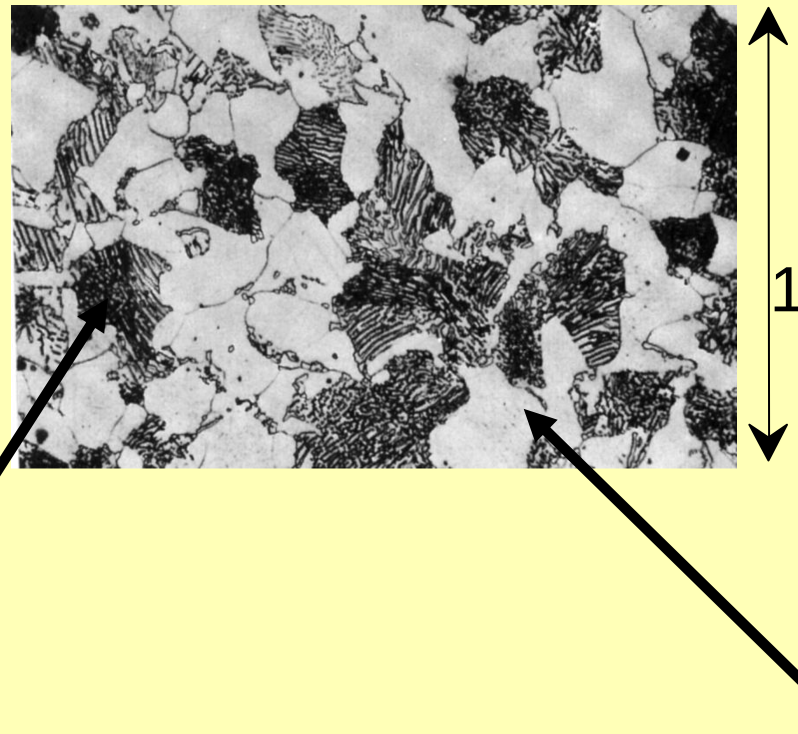
Hypoeutectoid Steel



$w_{pearlite} = w_\gamma$

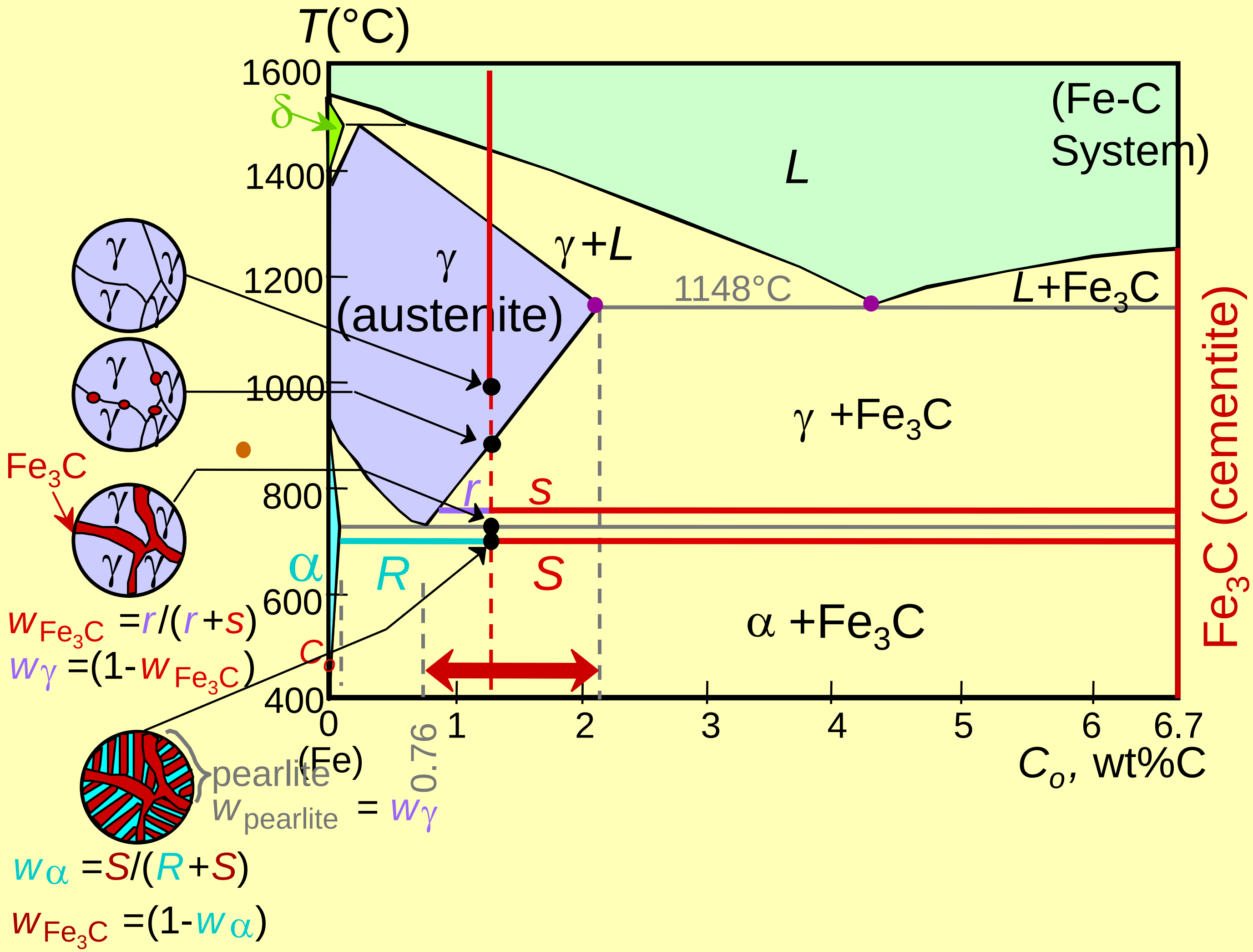
$w_\alpha = S/(R+S)$

$w_{Fe_3C} = (1 - w_\alpha)$

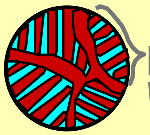


proeutectoid phase – the first phase that forms upon cooling the solid

Hypereutectoid Steel



Hypereutectoid Steel



$w_{pearlite} = w_\gamma$

$w_\alpha = S/(R+S)$

$w_{Fe_3C} = (1-w_\alpha)$

Example

For a 99.6 wt% Fe-0.40 wt% C at a temperature just below the eutectoid, determine the following

a) the amount of pearlite and proeutectoid ferrite (α) per 100 g of steel

b) composition of Fe_3C and ferrite (α)

c) the amount of carbide (cementite) in grams that forms per 100 g of steel

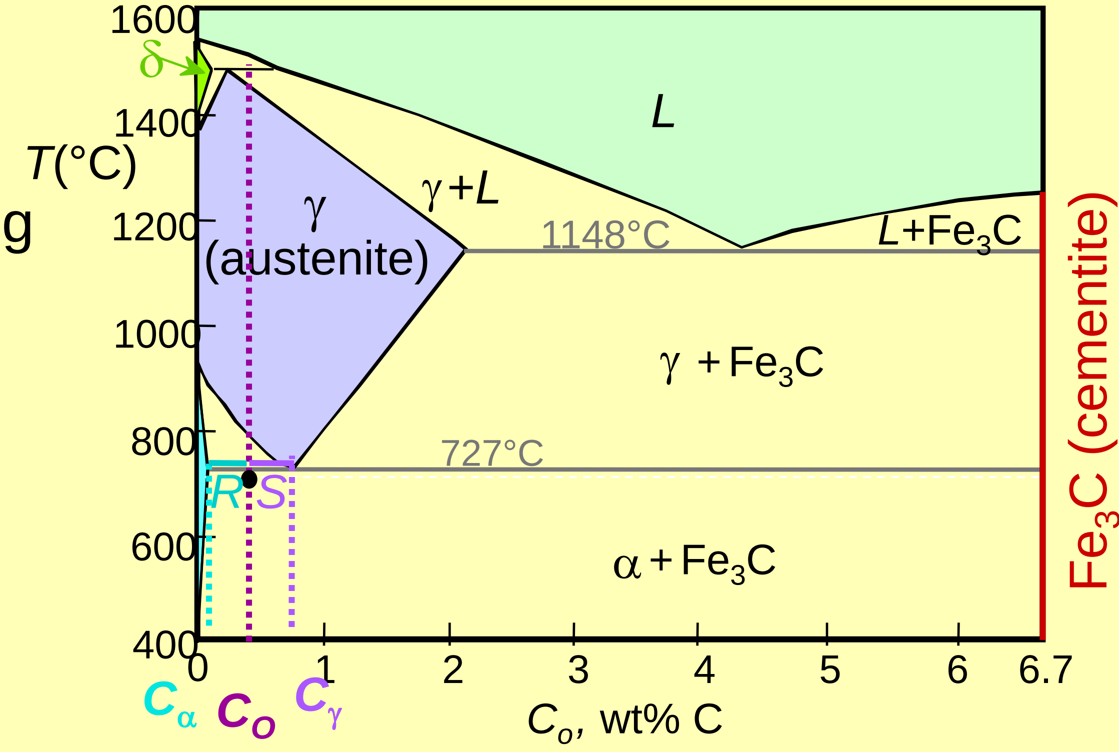
Solution

a. **the amount of pearlite and proeutectoid ferrite (α)**

note: amount of pearlite = amount of γ just above T_E

C_o = 0.40 wt% C
C_α = 0.022 wt% C
$C_{pearlite} = C_\gamma$ = 0.76 wt% C

$$\frac{\gamma}{\gamma+\alpha} = \frac{C_o - C_\alpha}{C_\gamma - C_\alpha} \text{ x } 100 = 51.2 \text{ g}$$



pearlite = 51.2 g
proeutectoid α = 48.8 g

Solution - continued

b) composition of Fe_3C and ferrite (α)

c) the amount of carbide (cementite) in grams that forms per 100 g of steel

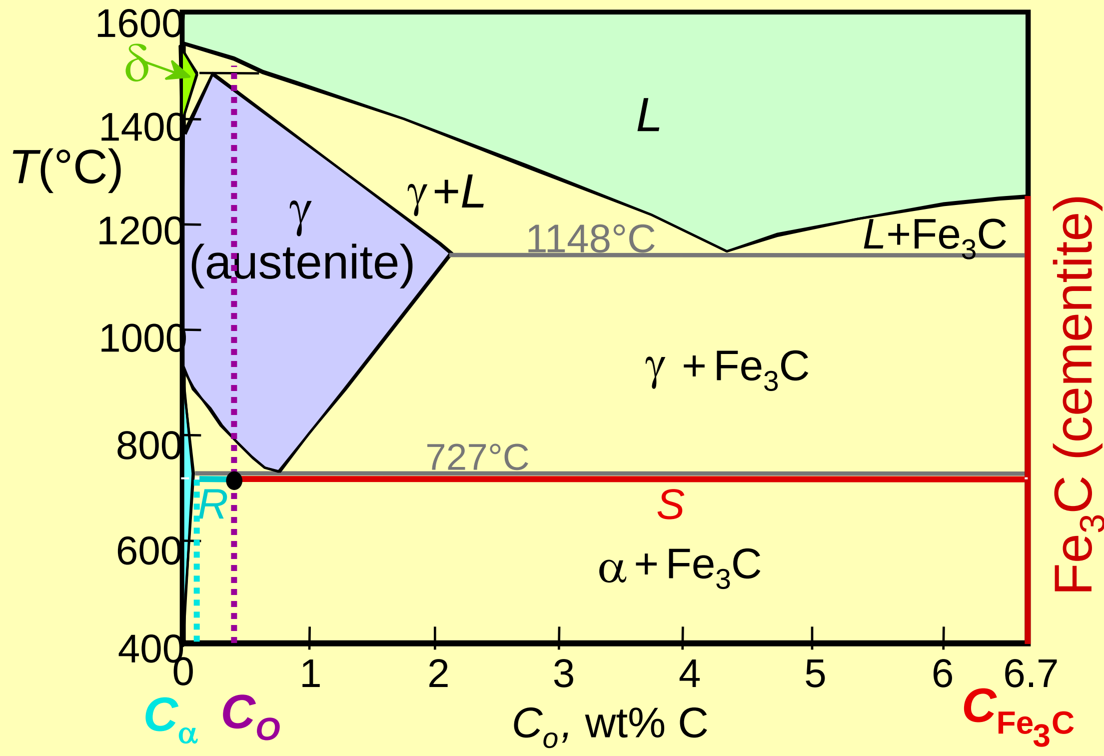
C_O = 0.40 wt% C
C_α = 0.022 wt% C
C_{Fe_3C} = 6.70 wt% C

$$\frac{Fe_3C}{Fe_3C + \alpha} = \frac{C_o - C_\alpha}{C_{Fe_3C} - C_\alpha} x100$$

$$= \frac{0.4 - 0.022}{6.7 - 0.022} x\, 100 = 5.7\text{g}$$

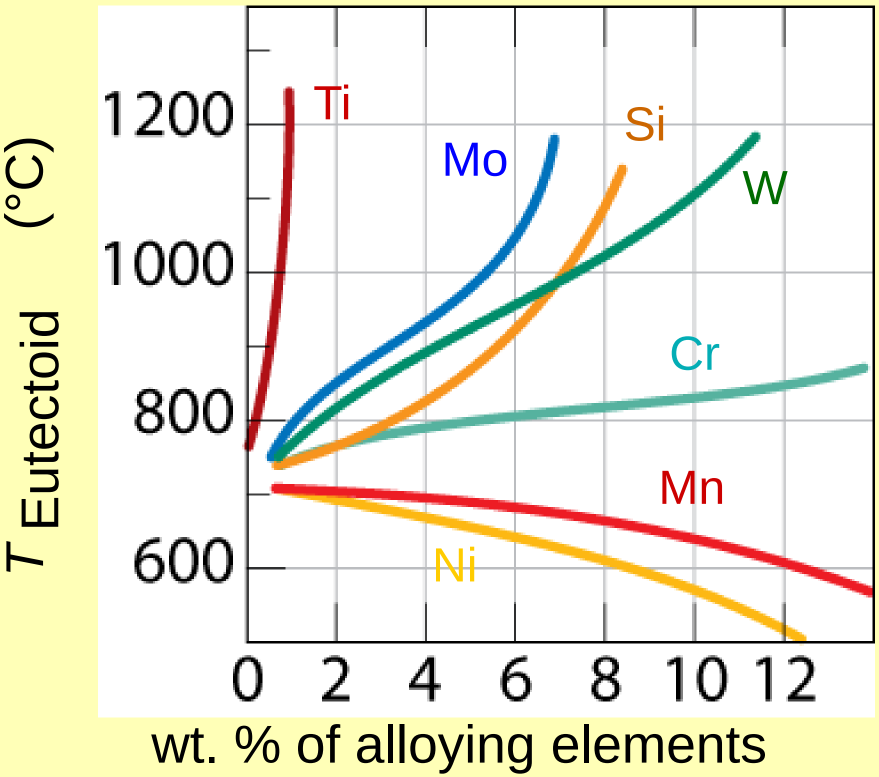
$Fe_3C = 5.7$ g

$\alpha = 94.3$ g

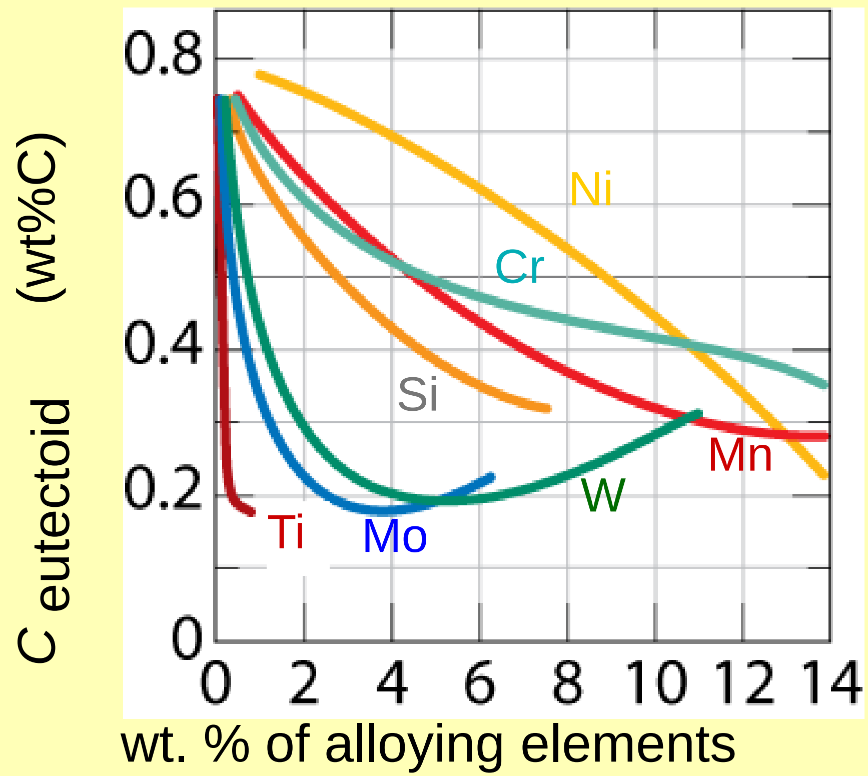


Alloying Steel with More Elements

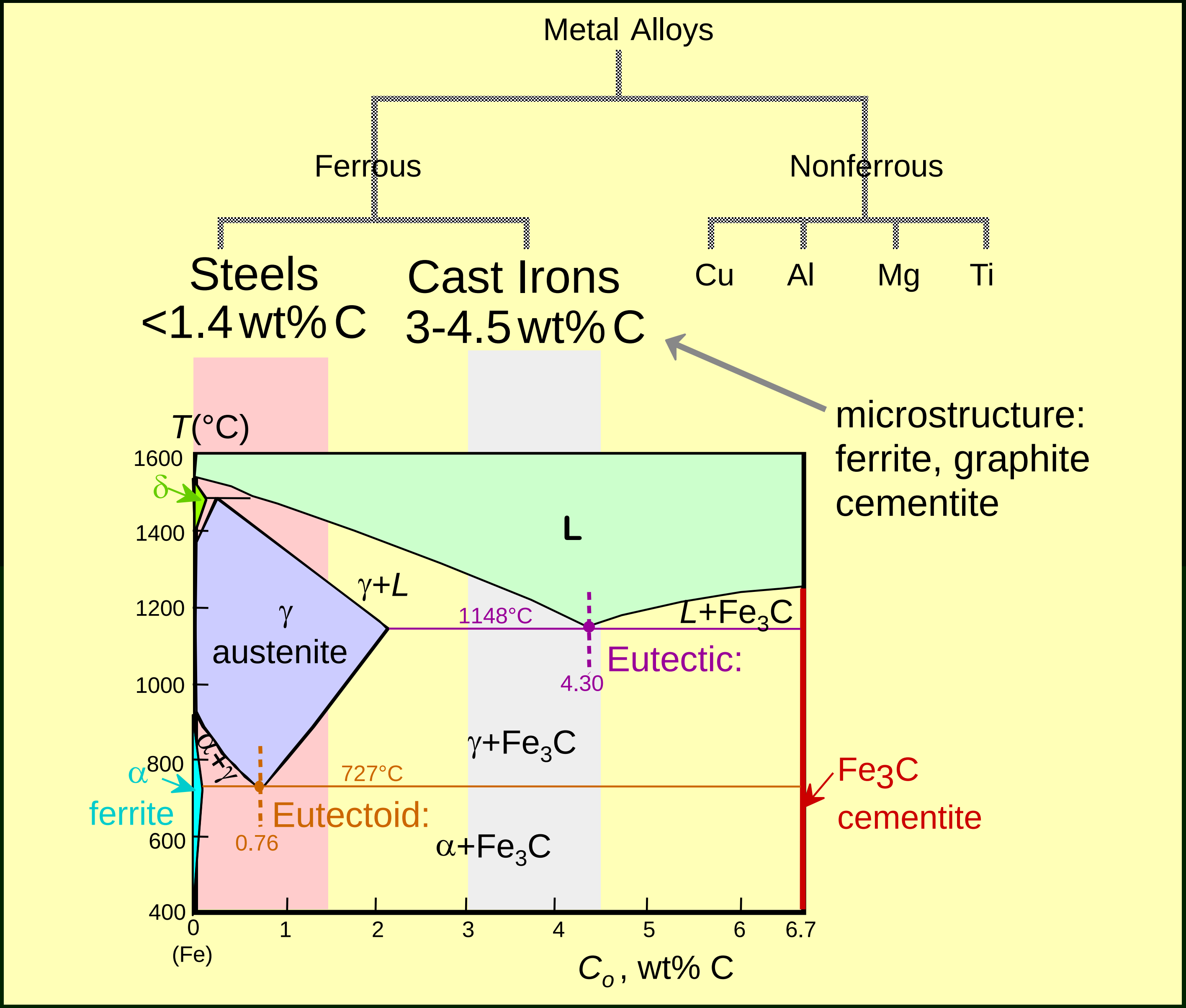
- $T_{eutectoid}$ changes:



- $C_{eutectoid}$ changes:



Taxonomy of Metals



Steels

	Low Alloy						High Alloy
	low carbon <0.25 wt% C		Med carbon 0.25-0.6 wt% C		high carbon 0.6-1.4 wt% C		
Name	plain	HSLA	plain	heat treatable	plain	tool	austenitic stainless
Additions	none	Cr,V Ni, Mo	none	Cr, Ni Mo	none	Cr, V, Mo, W	Cr, Ni, Mo
Example	1010	4310	1040	4340	1095	4190	304
Hardenability	0	+	+	++	++	+++	0
TS	-	0	+	++	+	++	0
EL	+	+	0	-	-	--	++
Uses	auto struc. sheet	bridges towers press. vessels	crank shafts bolts hammers blades	pistons gears wear applic.	wear applic.	drills saws dies	high T applic. turbines furnaces V. corros. resistant

increasing strength, cost, decreasing ductility →

Steel Types

(…for your information only… Not required for the examination!)

STEEL & ALLOY SELECTOR

BLACK CARBON STEELS

	1020	Low carbon steel suitable for parts not requiring high strength. Typical ultimate tensile range 380-450 MPa. Suitable for welded components.	C .20, Mn .60
	1045	Medium carbon steel supplied as rolled with an ultimate tensile strength of 550-650 MPa. Suitable for flame or induction hardening.	C .45, Mn .75

BRIGHT STEELS

MARKING	1004	Low carbon steel with excellent surface finish. Easy to weld and can be case hardened.	C, Mn
	1020	Cold finished mild steel, easy to weld, easy to machine and can be case hardened.	C .20, Mn .60
WHITE	1030	Suitable for similar components as 1020 but requiring a slightly higher tensile strength. Can be welded. Not suitable for case hardening.	C .20, Mn .60
	1040	Medium carbon steel for shafts and parts requiring 620MPa. Can be welded with precaution.	C .20, Mn .75
	1045	Similar to 1040 but with increased carbon, making this steel suitable for flame or induction hardened parts.	C .45, Mn .75, Si .25
	S1214	Standard general purpose free machining steel. S1214 responds well to case hardening.	C .15, Mn 1.00, S .30
	S12L14	Free-cutting steel with a lead addition to enhance machining characteristics. Ideal feedstock for bar automatics.	C* .15, Mn 1.25, S .25, Pb .25

ALLOY CASE HARDENING STEELS

WHITE	8620	Economical steel for production case hardened components. Finds wide use in automotive gears and races.	C .20, Mn .8, Ni .50, Cr .50, Mo .20
	X3312 EN36	Suitable for highly stressed gears in trucks and earthmoving equipment, pins and bushes.	C .12, Mn .50, Ni 3.20, Cr .90
WHITE	X4317 17CrNiMo6	Similar applications to EN36. Suitable for large gears and pinions that need very deep case depths.	C .17, Mn .50, Cr 1.65, Mo .80, Ni 1.55
	X9315 EN39B	Used for highly stressed gears, shafts and rock drills.	C .15, Mn .35, Cr 1.20, Mo .20, Ni 4.10

HIGH TENSILE STEELS

Limiting ruling section applies on diameter

	4140	850–1000 MPa UTS	Economical general purpose high tensile steel used for axles, pins, gears and light duty roll form sets.	C .40, Mn .80, Cr .90, Mo .20
	4340	930–1080 MPa UTS	Nickel, chromium and molybdenum high tensile steel used for components requiring higher strength than 4140.	C .40, Mn .80, Ni 1.80, Cr .80, Mo .25
	X9931 EN25	930–1080 MPa UTS	Similar applications to 4340 and suitable for severe duties requiring strength and toughness in larger cross sections.	C .30, Mn .60, Ni 2.50, Cr .50, Mo .50
	X9940 EN26	1080–1230 MPa UTS	Suitable for applications requiring high tensile strength and where high surface pressures exist, such as heavy gears and shafts.	C .40, Mn .60, Ni 2.50, Cr .50, Mo .50

CHROMIUM PLATED STEEL (CROMAX®)

280	CROMAX* 280	Micro alloyed base steel, ground and hard chromium plated. This medium tensile steel is easily welded and is suitable for hydraulic piston rods.	C .18, Mn 1.50, V .80
327	CROMAX* 327	Alloy high tensile steel, 850–1000 MPa ultimate tensile strength, ground and chromium plated for heavy duty piston rods.	C .40, Mn .80, Cr 1.00, Mo .20
482	CROMAX* 482	High core strength 850–1000 MPa ultimate tensile strength base steel, induction case hardened 55RC minimum. Used for piston rods, pivot and bucket pins.	C .42, Mn 1.75, V 1.00

CAST IRON

	T250	Continuous cast iron bar free from casting shrinkage. Used for high speed machining. Applications include V-pulleys, gears and sprockets.	
	ST1 (SG)	Ductile iron, the graphite occurs as spheroids. ST1 has higher strength and ductility compared to grey iron. Used for pump bodies and glands.	

BRONZE

MARKING	LG2	General purpose leaded gunmetal. Excellent machining characteristics, medium strength and good pressure tightness. Used for bushings, bearings and light duty gears.	Cu 85.00, Sn 5.00, Zn 5.00, Pb 5.00
MARKING	PB1	Phosphor bronze with good machining characteristics. High strength and good resistance to seawater and brine corrosion. Used for pump and valve components.	Cu 88.10, Sn 11.00, P .90

SPRING STEELS

MARKING	1055	Supplied spheroidised annealed as strip. Suitable for spring components that must be formed or drawn prior to heat treatment.	C .55, Mn .75
MARKING	CRINOLINE S82	A prehardened and tempered spring steel strip. Used for flat and coil springs, spring fasteners and band knives.	C .78, Mn .75
MARKING	S100	Similar applications to Crinoline. Steel has higher carbon content, making material suitable for band knives and trowel floats.	C .95, Mn .40
WHITE	9261	Silicon and manganese alloy supplied as rolled. Suitable for automotive leaf and coil springs and agricultural tools.	C .60, Si 1.95, Mn .90, Cr .20

COLD WORK TOOLSTEELS

MARKING	CPM 10V	Powder metallurgy toolsteel with extremely high carbon and vanadium. Used for tools requiring maximum abrasion resistance, such as barrel liners and apelletiser knives.	C 2.45, Cr 5.25, Mo 1.30, V 9.75
MARKING	CPM 9V	Similar to CPM 10V but with lower carbon and vanadium. Recommended for tools requiring unique toughness and wear resistance, such as shears and nail headers.	C 1.80, Cr 5.25, Mo 1.30, V 9.00
	2436 (D6)	Conventional high-carbon high-chromium toolsteel. Typical uses include blanking and drawing dies, brick liner mould plates, shears and small form rollers.	C 2.10, Cr 11.50, W .70
	2379 (D2)	Standard air hardening 12% chromium toolsteel. An ideal selection for processing stock thickness up to 3mm. Used for press tools, shear blades and roll formers.	C 1.50, Cr 12.20, Mo .95, V .95
MARKING	2363 (A2)	Similar application as 2379 but lower carbon and chromium provide for increased toughness. Used for press tools and shear blades.	C 1.00, Cr 5.10, Mo 1.15, V .20
	2510 (01)	General purpose oil hardening toolsteel. Used for blanking dies, drill bushes and gauges. Also available as flat ground stock.	C 1.05, Mn 1.15, Cr .50, W .50, V .20
	S5	A shock-resisting steel suitable for general toolroom work and applications demanding toughness such as heavy scrap shears, punches and chisels.	C .60, Si 1.60, Mn .80, Cr .35, Mo .40, V .15

HOTWORK ALLOYS

MARKING	718	Nickel based super alloy, normally supplied solution treated and age hardened. Used for copper extrusion dies, dummy pads and inner liners.	Ni 52.5, Cr 19.0, Mo 3.0, Cb+Ta 5.1, bal. Fe
MARKING	286	Iron based super alloy normally supplied solution treated and aged. Used for brass and copper extrusion press liners.	Ni 25.50, Cr 14.75, Mo 3.00, Ti 2.15, bal. Fe
MARKING	R41	Nickel based super alloy normally supplied solution treated and aged. Used for selective brass extrusion dies and mandrels.	Cr 19.0, Co 11.0, Mo 9.6, Ti 3.15, Fe* 5.00, bal. Ni
MARKING	2367	Molybdenum enhanced hot work steel with superior hot strength compared to H13. Used for brass forging dies, die casting inserts and mandrels for copper extrusion.	C 0.38, Cr 5.00, Mo 3.00, V .60
	2344 (H13)	2344 has excellent resistance to shock and softening and resistance to heat checking. Used for aluminium extrusion tools, die casting dies and plastic moulds.	C 0.40, Cr 5.20, Mo 1.40, V 1.00
MARKING	9966 SUPER C	Newly developed hot working steel with enhanced impact resistance and toughness, combined with excellent hot strength. Ideal for forging dies with deep cavities.	C .30, Cr 1.50, Mo .80, V .30, S* .002, P* .003
	2714	Nickel alloy steel supplied prehardened and tempered to 1100–1350 N/mm². Used extensively for hot forging dies, tool holders and hot shears.	C 0.55, Mn .70, Cr 1.10, Mo .50, Ni 1.70, V .10

MOULD BLOCK STEELS

	2311 (P20)	High cleanliness, prehardened tool steel with high polishability. Used for plastic mould dies and high tensile applications.	C .40, Mn 1.45, Cr 1.95, Mo .20, S* .003, P* .025
	2312 (P20+S)	Similar to 2311 grade but with the addition of sulphur to aid machinability. Not suitable for highly polished moulds. Used for support tools.	C .40, Mn 1.50, Cr 1.90, Mo .20, S .075, P* .030
MARKING	2738 (P20+Ni)	High integrity prehardened plastic mould steel with excellent polishability. Used for large plastic mould blocks such as bumper moulds.	C .40, Mn 1.40, Cr 1.95, Mo .20, Ni 1.15, P* .025, S* .003
MARKING	2764 (P21)	Low distortion air hardening case carburising steel. Used for compression moulds with high loads and simultaneous abrasion.	C .19, Ni 4.00, Cr 1.30, Mo .20
MARKING	2316	Martensitic stainless steel suitable for plastic moulds and inserts for moulding PVC and other sensitive plastics. Can be hardened to 55HRC.	C .28, Cr 14.20, Mo 1.10

STAINLESS STEELS

	303	Free machining austenitic stainless. It is used where extensive machining is involved.	C .08, Mn 1.90, Ni 9.00, Cr 18.00, S .25
	304	A general purpose austenitic stainless steel used for the food and chemical industries.	C .06, Mn 1.70, Ni 9.50, Cr 18.00
	304L	Low carbon variant of 304 type, minimises carbide precipitation during welding. Hence improved corrosion resistance and improved formability over 304.	C* .03, Mn 2.00, Ni 9.50, Cr 25.00
	310	Austenitic heat resisting stainless, suitable for continuous service at 850–1000°C. Use in the range of 550–800°C should be avoided.	C .08, Mn 1.30, Ni 20.00, Cr 25.00
	316	Austenitic 18-8 stainless with molybdenum to enhance weldability and resistance to pitting corrosion. Recommended for marine and chemical equipment.	C .06, Mn 1.70, Ni 12.00, Cr 17.00, Mo 2.25
	321	A titanium stabilised grade suitable for welding. Ideal for heavy fabrications.	C .07, Mn 1.70, Ni 10.00, Cr 18.00, Ti .50
	416	A martensitic free-machining stainless which is suitable for parts that require machining and moderate tensile strength.	C .10, Mn 1.10, Cr 12.50, S .20
MARKING	420C	High carbon martensitic stainless. Used where higher tensile strength is required. Used for pump and valve parts.	C .30, Mn .70, Cr 13.00
MARKING	420V	A powder metallurgy steel designed for tools requiring abrasion and corrosion resistance.	C 2.20, Cr 13.00, V 9.00, Mo 1.00
	431	A high tensile stainless developed for pump shaft applications. Corrosion resistance is slightly lower than 304.	C .18, Mn .70, Ni 2.20, Cr 16.00
	630PH	A precipitation hardening stainless with high strength after aging. Corrosion resistance similar to Type 304. Used for propeller shafting and valve parts.	C .05, Mn .40, Ni 4.00, Cr 16.00, Cu 3.75, Nb .25, Si .40
MARKING	DUPLEX UNS S31803	Stainless with a duplex microstructure of ferrite and austenite. The high chromium and molybdenum enhance the steel's ability to resist pitting corrosion.	C* .03, Cr 22.00, Mo 3.00, Ni 5.50, N .14
MARKING	SUPER DUPLEX UNS S32760	Stainless with duplex microstructure. Alloy additions enhance corrosion resistance and tensile strength. Excellent resistance to pitting and stress corrosion.	C* .03, Cr 25.00, Mo 3.50, Ni 7.00, W .75, Cu .75, N .25