

# Chapter 9: Phase Diagrams

## ISSUES TO ADDRESS...

When we combine two elements, what equilibrium state do we get?

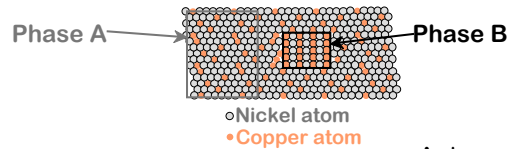
In particular, pick

- a composition (e.g., wt%Cu-wt%Ni)
- a temperature (T)

How many phases do we get?

What is:

- the weight fraction of each phase (e.g., wt%A-wt%B)?
- the composition (e.g., wt%Cu-wt%Ni) of each phase?



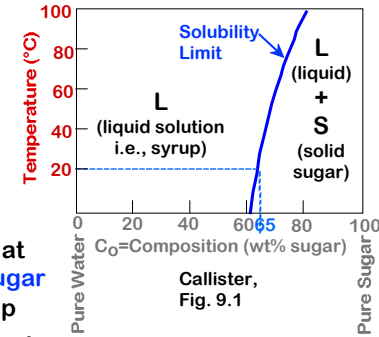
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# The Solubility Limit

- Max. concentration for which only a solution occurs.

- Phase Diagram: Water-Sugar System



- Example:
  - What is the solubility limit at 20°C? Answer: 65wt% sugar
  - if  $C_0 < 65\text{wt\%}$  sugar: syrup
  - if  $C_0 > 65\text{wt\%}$  sugar: syrup + sugar

- Solubility limit increases with T

- e.g., if  $T = 100^\circ\text{C}$ , solubility limit = 80wt% sugar

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# Components and Phases

- Components:

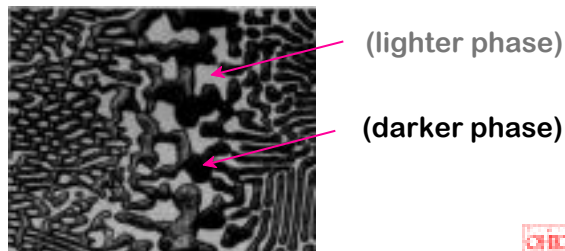
The elements or compounds which are mixed initially (e.g., Al and Cu)

- Phases:

The physically and chemically distinct material regions that result (e.g., and ).

Aluminum-Copper Alloy

Callister, Fig. 9.0 3rd ed.



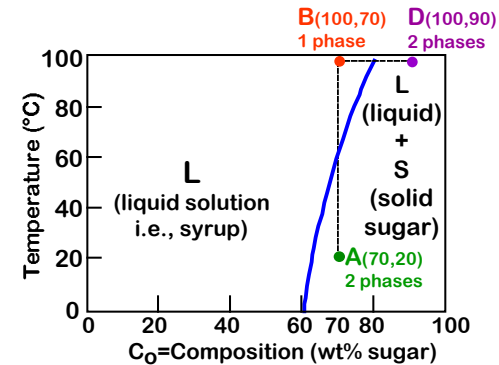
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# Effect of T, Composition ( $C_0$ )

- Changing T can change # of phases: path A to B
- Changing  $C_0$  can change # of phases: path B to D

water-sugar system

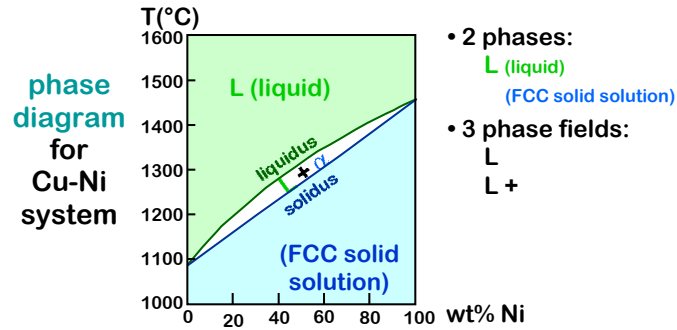


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## Phase Diagrams

- Information about phases as function of T, C<sub>0</sub>, P
- For this course:
  - binary systems: just 2 components
  - independent variables: T and C<sub>0</sub> (P = 1atm is always used).



- 2 phases:
  - L (liquid)
  - (FCC solid solution)
- 3 phase fields:
  - L
  - L +

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## Phase Diagrams: # and Types of Phases

- RULE #1:** If we know T and C<sub>0</sub>, then we know: the # and types of phases present.

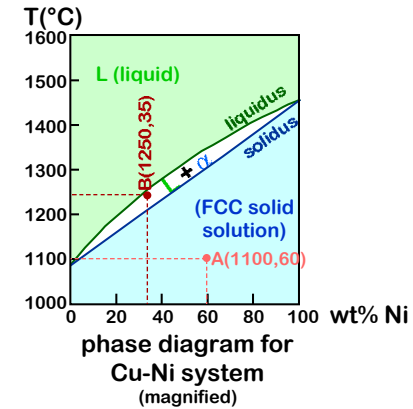
Examples:

A(1100, 60):

1 phase:

B(1250, 35):

2 phases: L +



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## Phase Diagrams: Composition of Phases

- Rule#2:** If we know T and C<sub>0</sub>, then we know: the composition of each phase.

- Examples: Assume

C<sub>0</sub> = 35wt%Ni

At T<sub>A</sub>:

Only Liquid (L)

C<sub>L</sub> = C<sub>0</sub> (= 35wt% Ni)

At T<sub>D</sub>:

Only Solid ( )

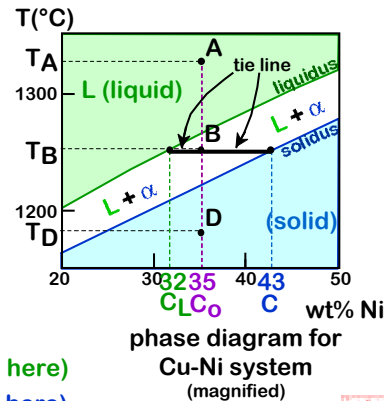
C = C<sub>0</sub> (= 35wt% Ni)

At T<sub>B</sub>:

Both L and

C<sub>L</sub> = C<sub>liquidus</sub> (= 32wt% Ni here)

C = C<sub>solidus</sub> (= 43wt% Ni here)



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## Phase Diagrams: Weight Fractions of Phases

- Rule#3:** If we know T and C<sub>0</sub>, then we know: the amount of each phase (given in weight %)

- Examples: Assume

C<sub>0</sub> = 35wt%Ni

At T<sub>A</sub>: Only Liquid (L)

W<sub>L</sub> = 100wt%, W = 0

At T<sub>D</sub>: Only Solid ( )

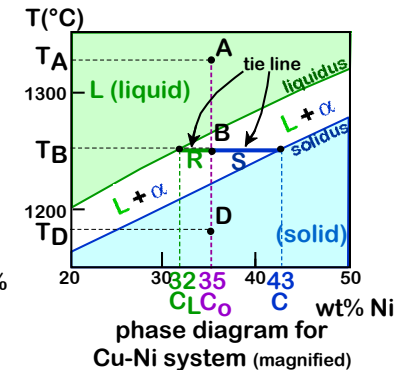
W<sub>L</sub> = 0, W = 100wt%

At T<sub>B</sub>: Both L and

$$W_L = \frac{S}{R+S} = \frac{43-35}{43-32} = 73\text{wt}\%$$

$$W = \frac{R}{R+S} = 27\text{wt}\%$$

THE "LEVER RULE"



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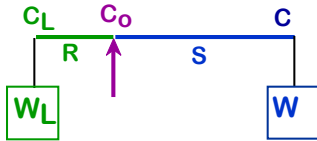
## The Lever Rule: A Proof

- Sum of weight fractions:  $W_L + W = 1$
- Conservation of mass (Ni):  $C_0 = W_L C_L + W C$
- Combine above equations:

$$W_L = \frac{C - C_0}{C - C_L} = \frac{S}{R+S}$$

$$W = \frac{C_0 - C_L}{C - C_L} = \frac{R}{R+S}$$

- A geometric interpretation:



moment equilibrium:

$$W_L R = W S$$

$$1 - W$$

solving gives Lever Rule

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## Example: Cooling in a Cu-Ni Binary

Phase diagram:  
Cu-Ni system

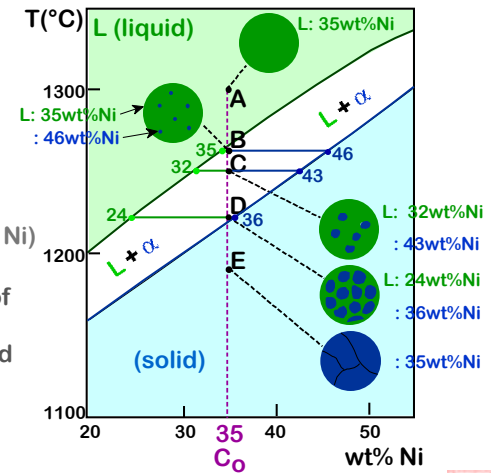
System is:

-binary

(2 components: Cu & Ni)

-isomorphous

(complete solubility of one component in another: phase field extends from 0 to 100wt% Ni)



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## Cored vs Equil. Solid Phases

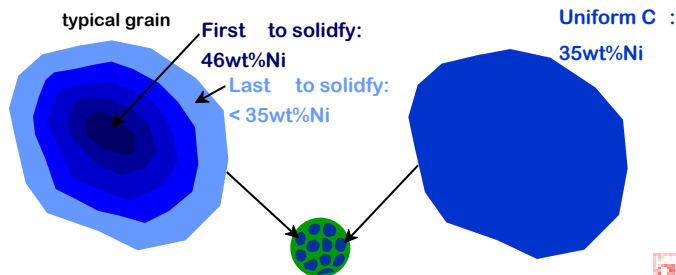
- C changes as we solidify

Cu-Ni case: First to solidify has  $C = 46\text{wt}\% \text{Ni}$

Last to solidify has  $C = 35\text{wt}\% \text{Ni}$

- Fast rate of cooling:  
Cored structure

- Slow rate of cooling:  
Equilibrium structure



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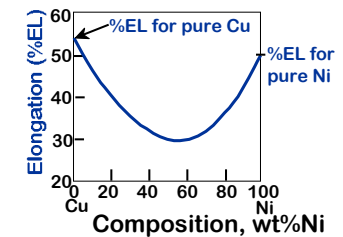
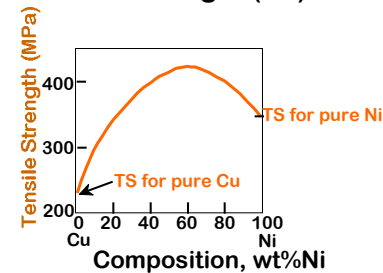


## Mechanical Properties: Cu-Ni System

- Effect of solid solution strengthening on:

-Tensile Strength (TS)

-Ductility (%EL, %AR)



-Peak as a function of  $C_0$

-Min. as a function of  $C_0$

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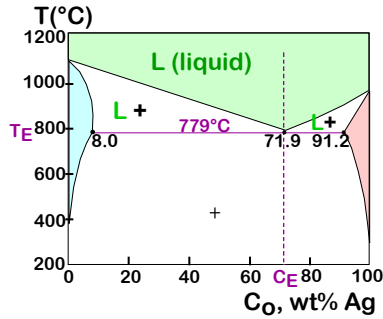
# Binary-Eutectic Systems

2 components

there is a special  $C_0$  with a min. melting T

## Ex.: Cu-Ag system

- 3 single phase regions (L,  $\alpha$ ,  $\beta$ )
- Limited solubility:
  - $\alpha$ : mostly Cu
  - $\beta$ : mostly Ni
- $T_E$ : No liquid below  $T_E$
- $C_E$ : Min. melting T

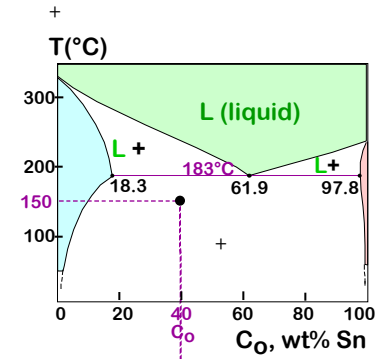


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## Ex: Pb-Sn Eutectic System

For a 40wt%Sn-60wt%Pb alloy at 150°C, find...

- the phases present:
- the composition of the phases



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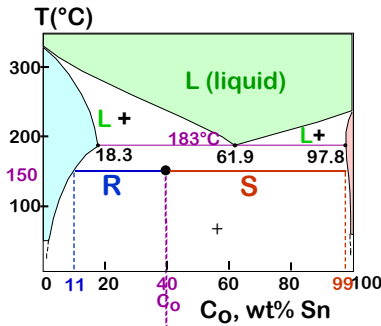
## Ex: Pb-Sn Eutectic System

For a 40wt%Sn-60wt%Pb alloy at 150°C, find...

- the phases present: +
- the composition of the phases:
  - $C = 11\text{wt}\%\text{Sn}$
  - $C = 99\text{wt}\%\text{Sn}$
- the relative amounts of each phase:

$$W = \frac{59}{88} = 67\text{wt}\%$$

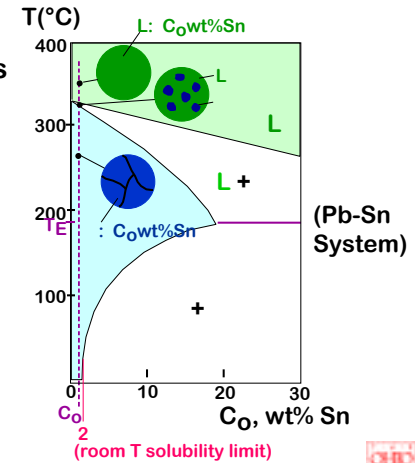
$$W = \frac{29}{88} = 33\text{wt}\%$$



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## Microstructures in Eutectic Systems-I

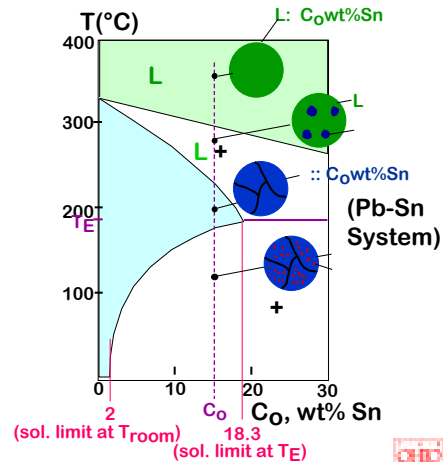
- $C_0 < 2\text{wt}\%\text{Sn}$
- Result: Polycrystal of grains



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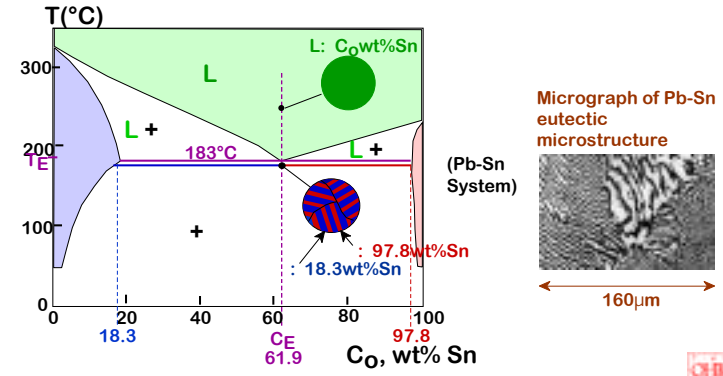
## Microstructures in Eutectic Systems-II

- $2\text{wt}\% \text{Sn} < C_0 < 18.3\text{wt}\% \text{Sn}$
- Result: polycrystal with fine crystals



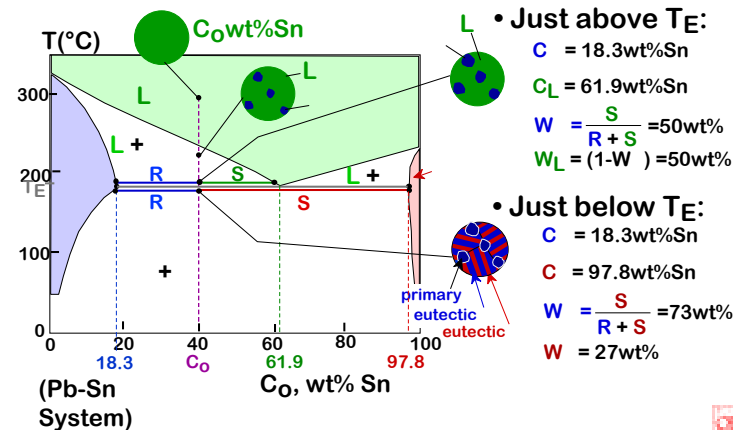
## Microstructures in Eutectic Systems-III

- $C_0 = C_E$
- Result: Eutectic microstructure -alternating layers of and crystals



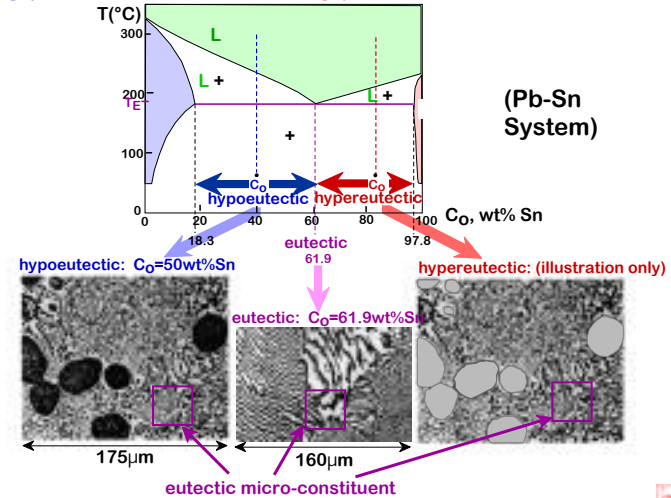
## Microstructures in Eutectic Systems-IV

- $18.3\text{wt}\% \text{Sn} < C_0 < 61.9\text{wt}\% \text{Sn}$
- Result: crystals and a eutectic microstructure



- Just above  $T_E$ :
  - $C = 18.3\text{wt}\% \text{Sn}$
  - $C_L = 61.9\text{wt}\% \text{Sn}$
  - $W = \frac{S}{R+S} = 50\text{wt}\%$
  - $W_L = (1-W) = 50\text{wt}\%$
- Just below  $T_E$ :
  - $C = 18.3\text{wt}\% \text{Sn}$
  - $C = 97.8\text{wt}\% \text{Sn}$
  - $W = \frac{S}{R+S} = 73\text{wt}\%$
  - $W = 27\text{wt}\%$

## Hypoeutectic and hypereutectic cases



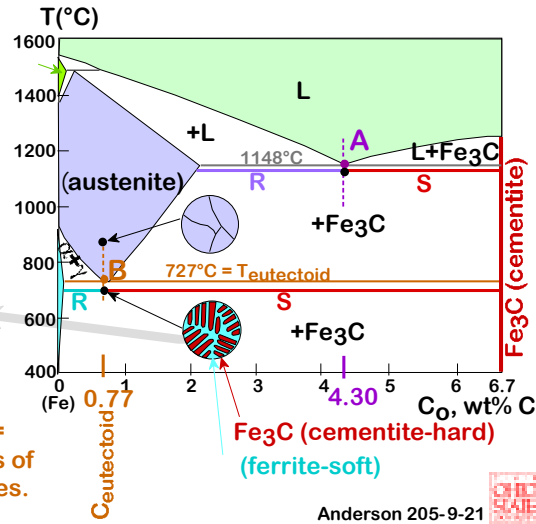
# Iron-Carbon (Fe-C) Phase Diagram

- 2 important points

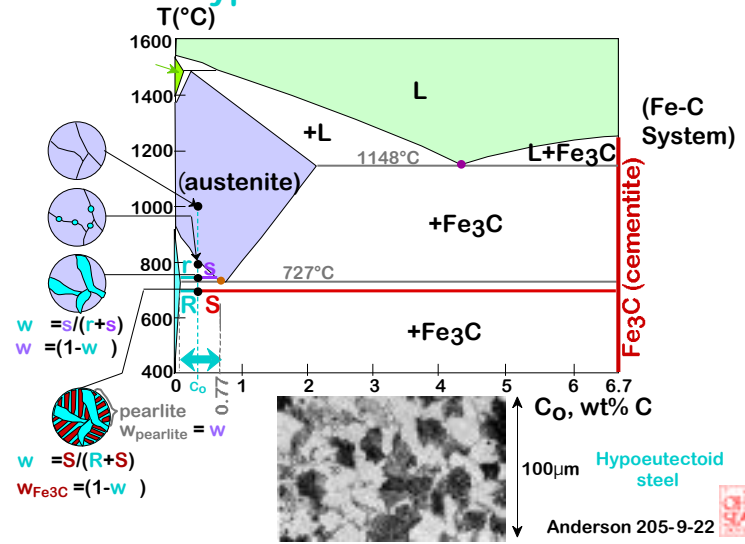
- Eutectic (A): L + Fe<sub>3</sub>C
- Eutectoid (B): +Fe<sub>3</sub>C



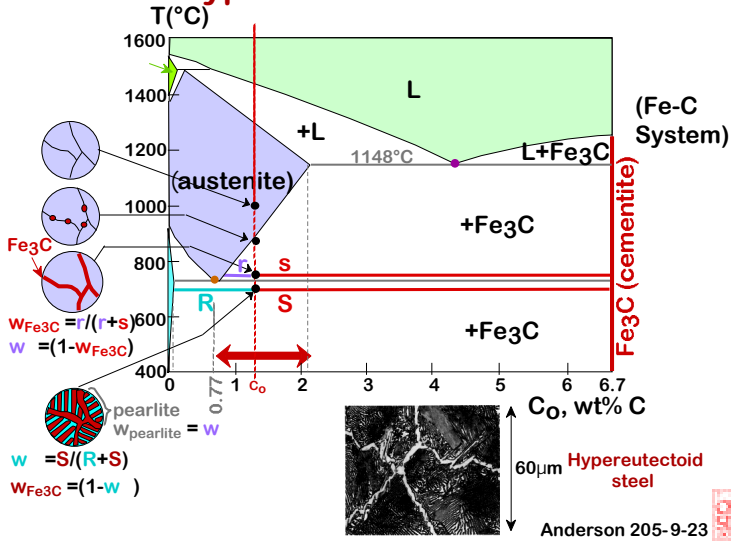
Result: Pearlite = alternating layers of and Fe<sub>3</sub>C phases.



# Hypoeutectoid steel

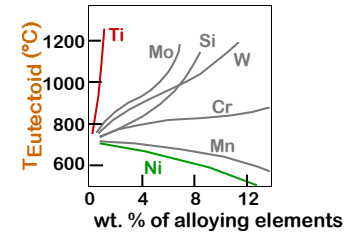


# Hypereutectoid steel

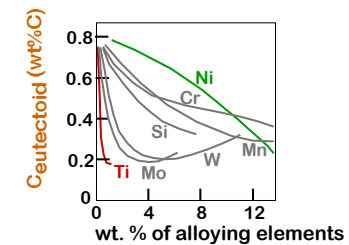


# Alloying Steel with additional elements

- T<sub>Eutectoid</sub> changes:



- C<sub>Eutectoid</sub> changes:



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