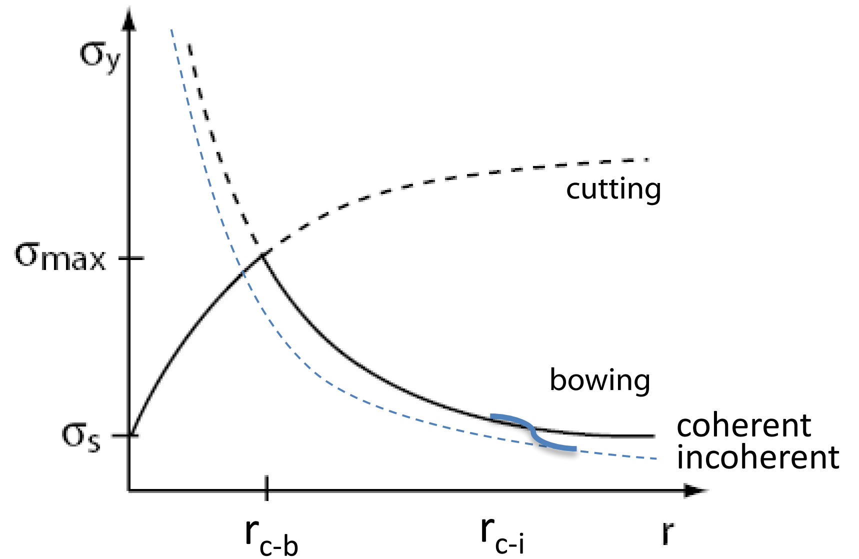
3.40 Lecture Summary 11/16/09

Better, Faster, Stronger…
How to Engineer Metals
With Thermo & Kinetics

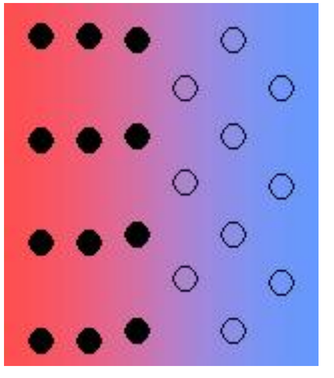
Contributions to Precipitation Hardening

- Particle Size
  - Shearablility
  - Coherency
- Ordering
- Modulus
- Volume Fraction



Courtesy of Krystyn Van Vliet. Used with permission.

Please see Fig. 3.47c in Porter, D., and K. Easterling.
Phase Transformations in Metals and Alloys
Boca Raton, FL: CRC Press, 2009.



Coherency:
Lattice strain

Coherent with Strain

Courtesy of DoITPoMS, University of Cambridge.
Used with permission.

D. Porter, K. Easterling. Phase transformations in metals and alloys. CRC Press 2000.
http://www.matsceng.ohio-state.edu/mse205/lectures/chapter10/index_chap10.htm

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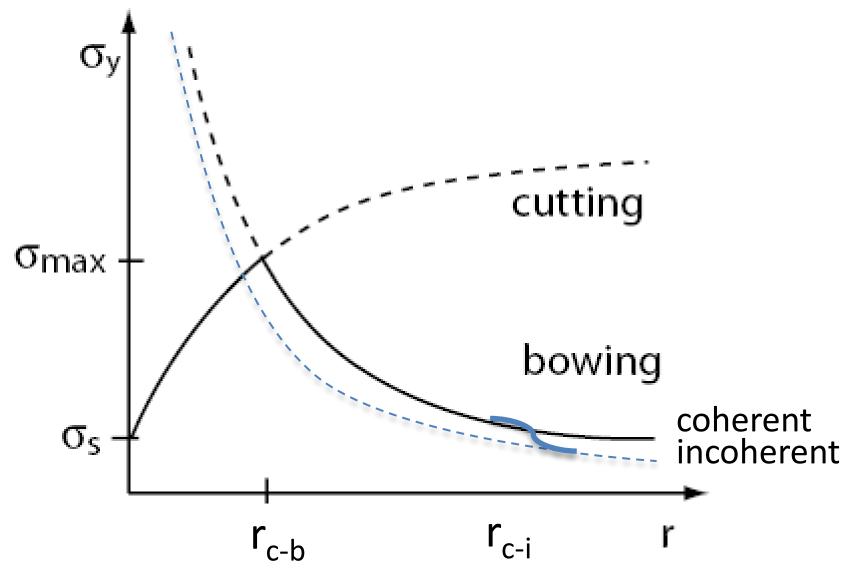


Courtesy of Krystyn Van Vliet. Used with permission.

How do we engineer metals for maximum strength?

Simple: Large number of particles with $r = r_{c\text{-}b}$

http://www.matsceng.ohio-state.edu/mse205/lectures/chapter10/index_chap10.htm

Thermodynamics: Phase Diagrams

What do we want?
Intermetallic:
Ordered phase
<u>Large V_f</u>

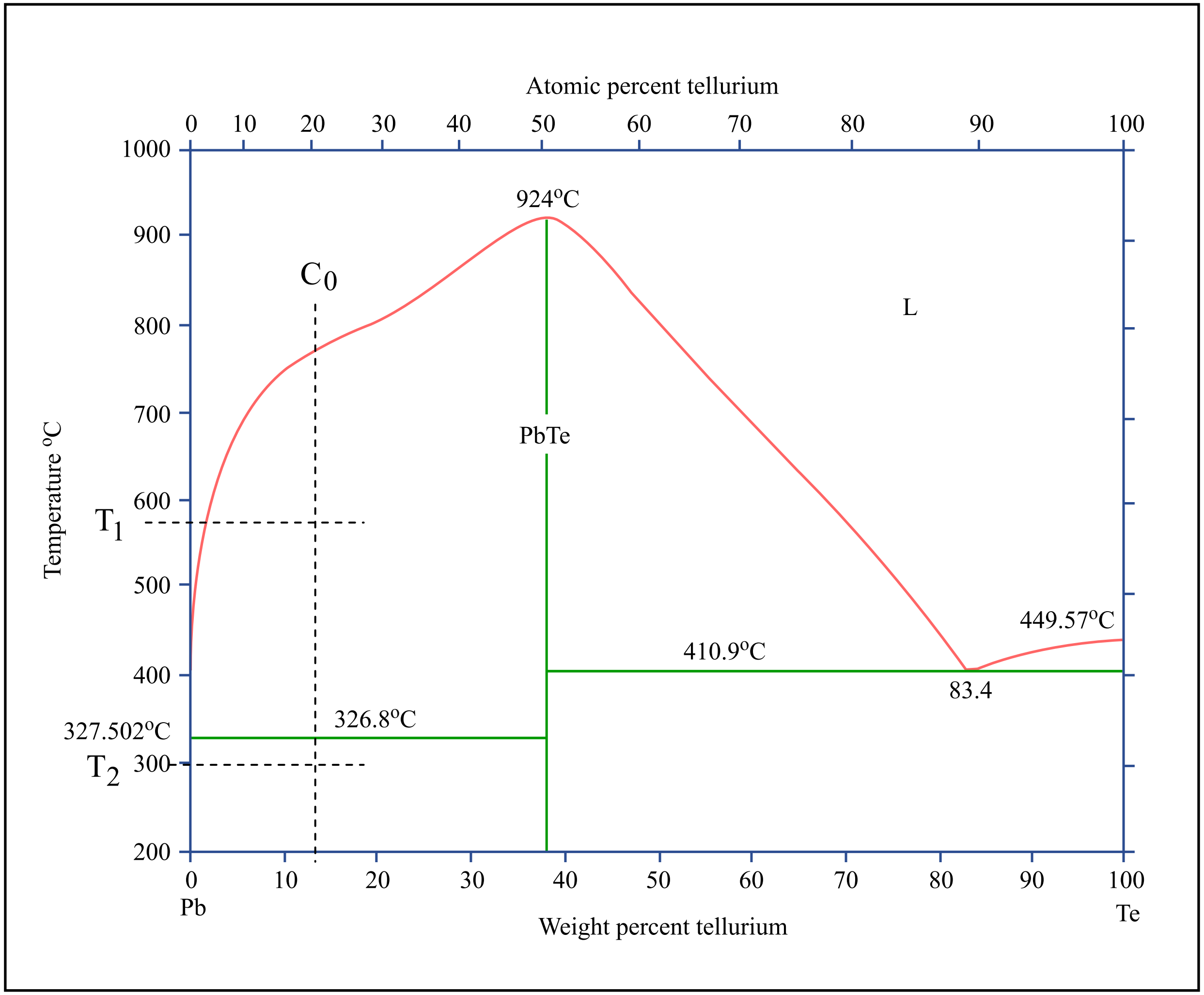


Figure by MIT OpenCourseWare. Adapted from *Vol. 3, Alloy Phase Diagrams, ASM Handbook.*
Materials Park, OH: ASM International, 2009.

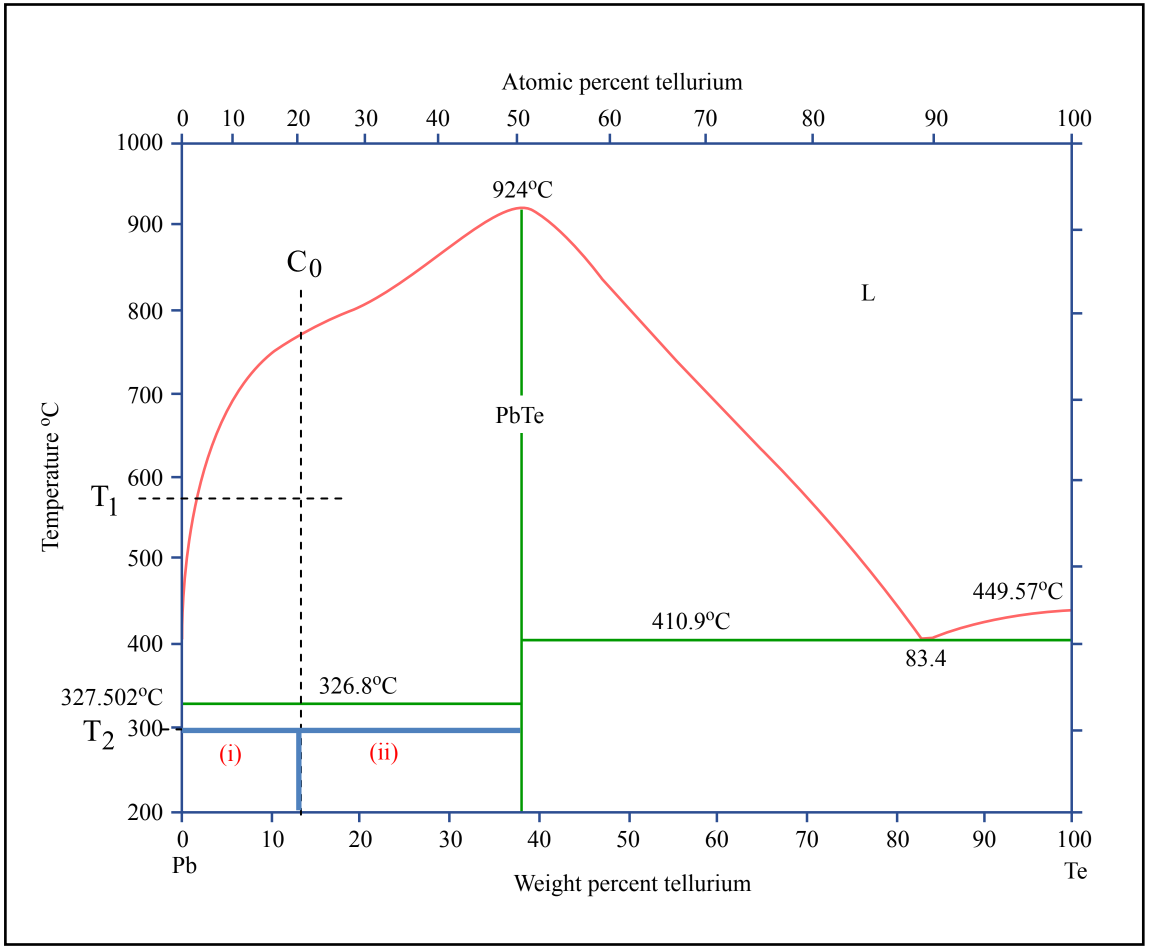
Please see "Microstructural Development: Basic Requirements for Aging. *aluMATTER*, University of Liverpool."

W. Hosford. Physical Metallurgy CRC Press, 2005

Thermodynamics: Phase Diagrams

Tie-Line Construction

$$V_f^{\beta} = \frac{i}{i + ii}$$



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Please see "Microstructural Development: Basic Requirements for Aging. *aluMATTER*, University of Liverpool."

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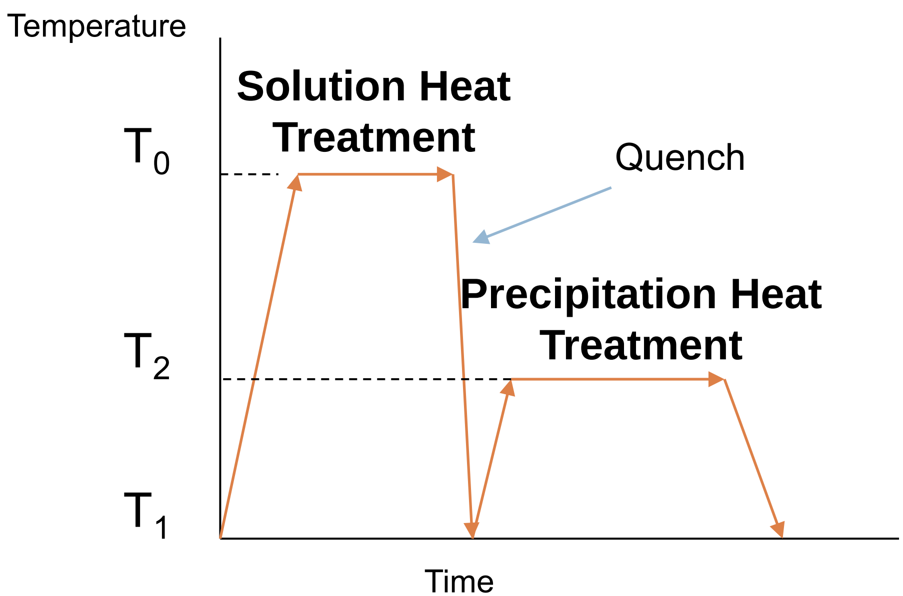
What about particle size: Kinetics

What do we want?

Large V_f of optimum particle size



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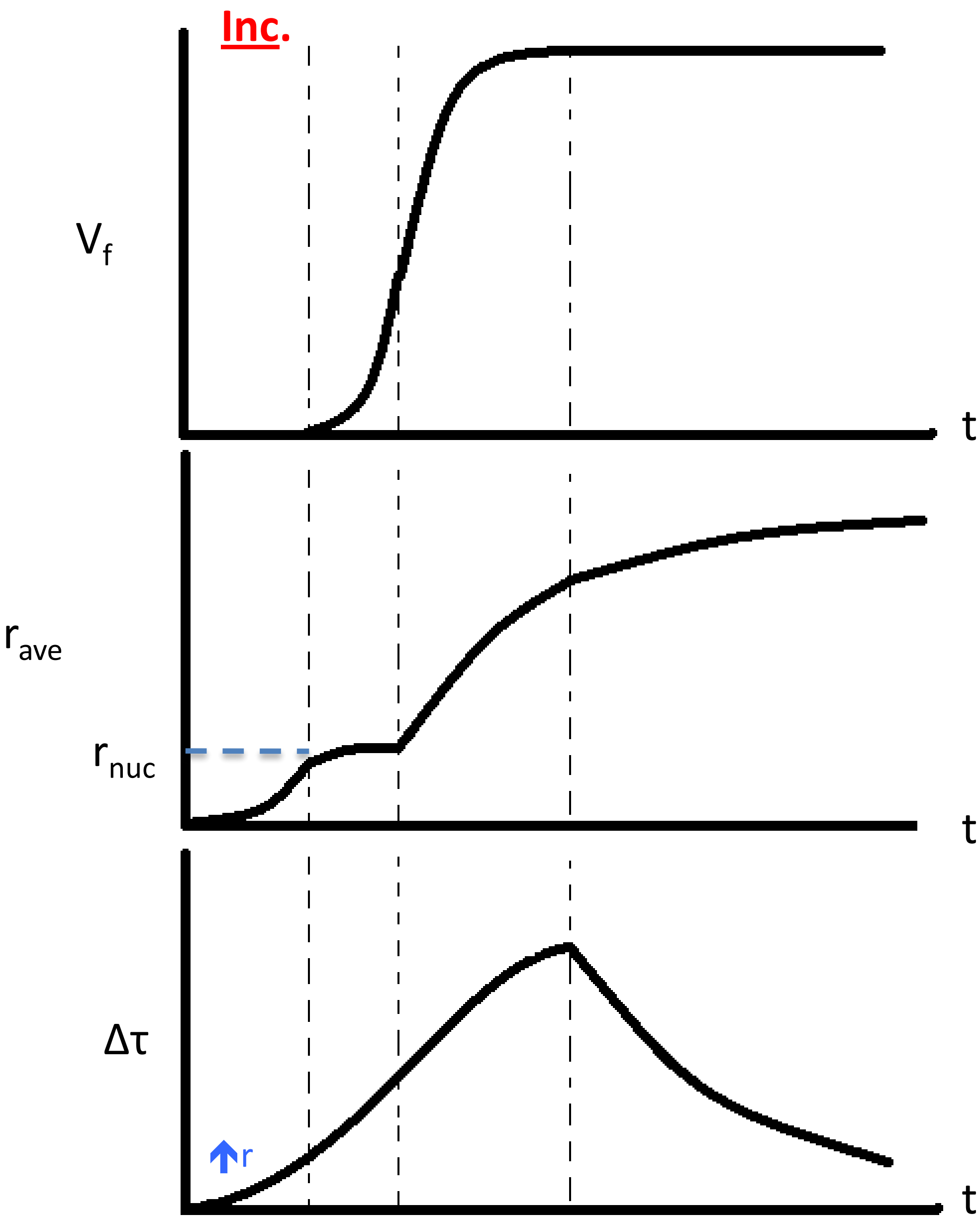
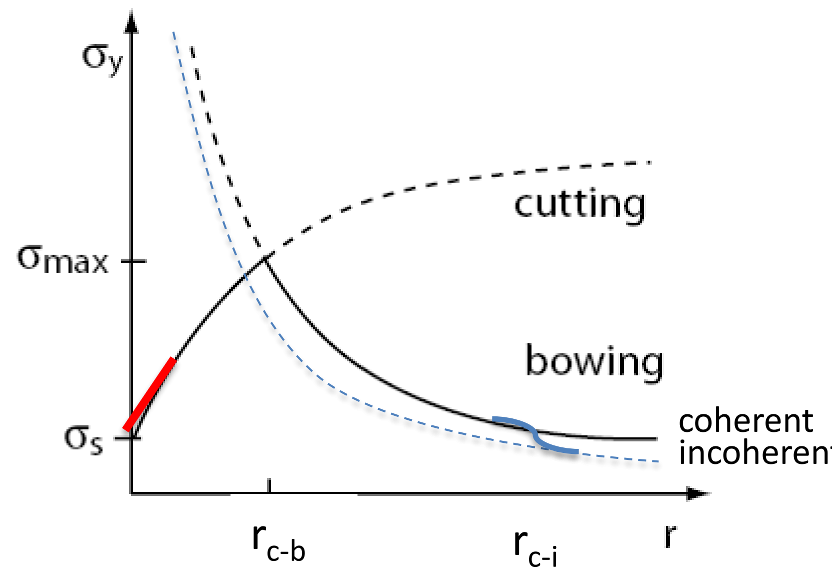
Used with permission. Please also see "Microstructural Development: Stages of Heat Treatment." *aluMATTER*, University of Liverpool.

http://www.uic.edu/classes/cemm/cemm470/Heat%20Treatment%20of%20Steels%20and%20Metallic%20Materials%5B1%5D.pdf

Precipitation Hardening: Kinetics





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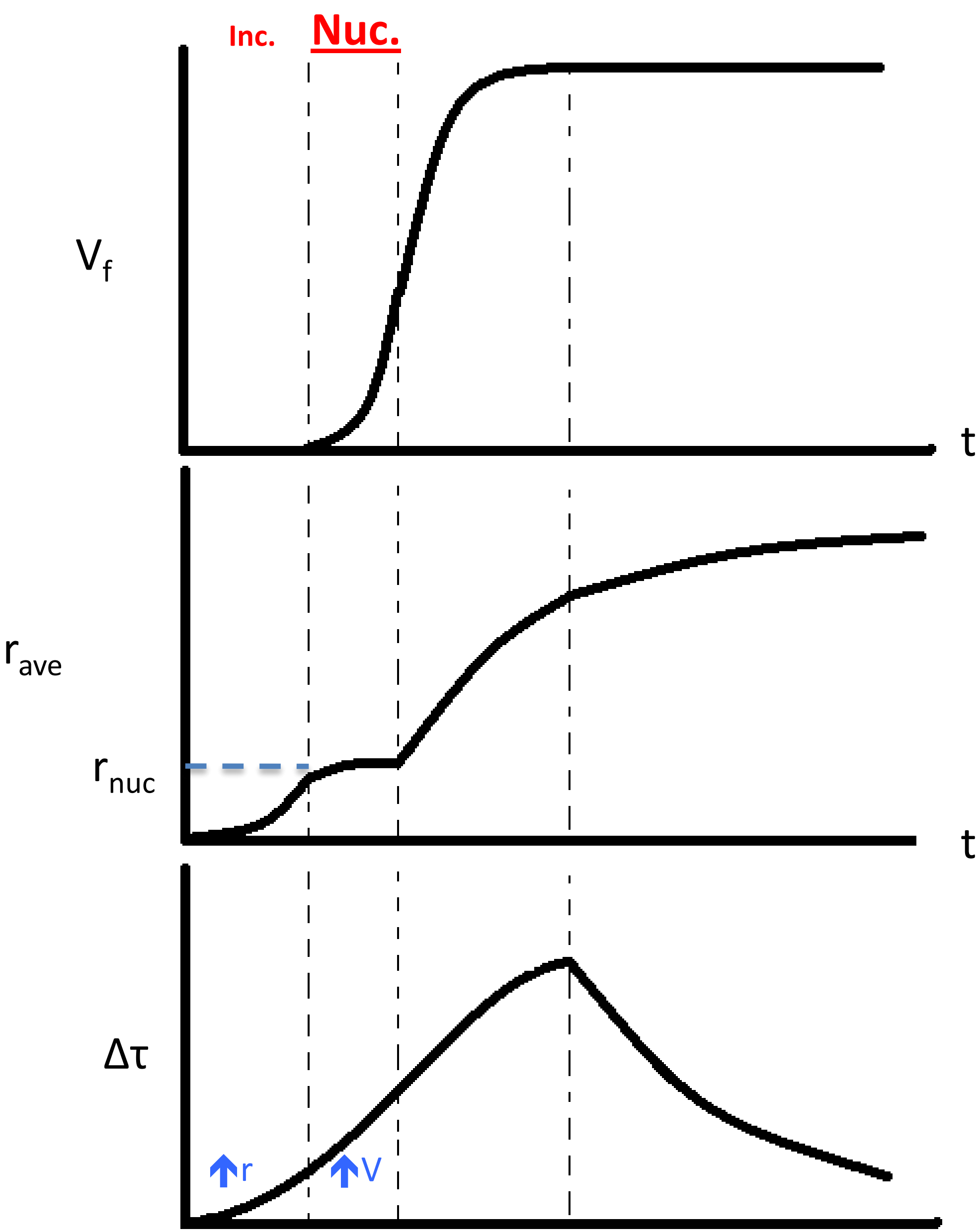
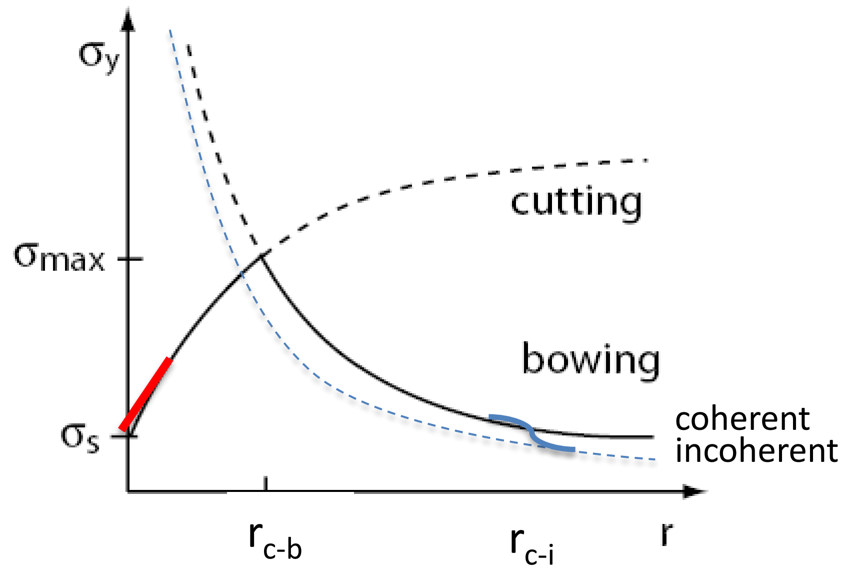
Precipitation Hardening: Kinetics





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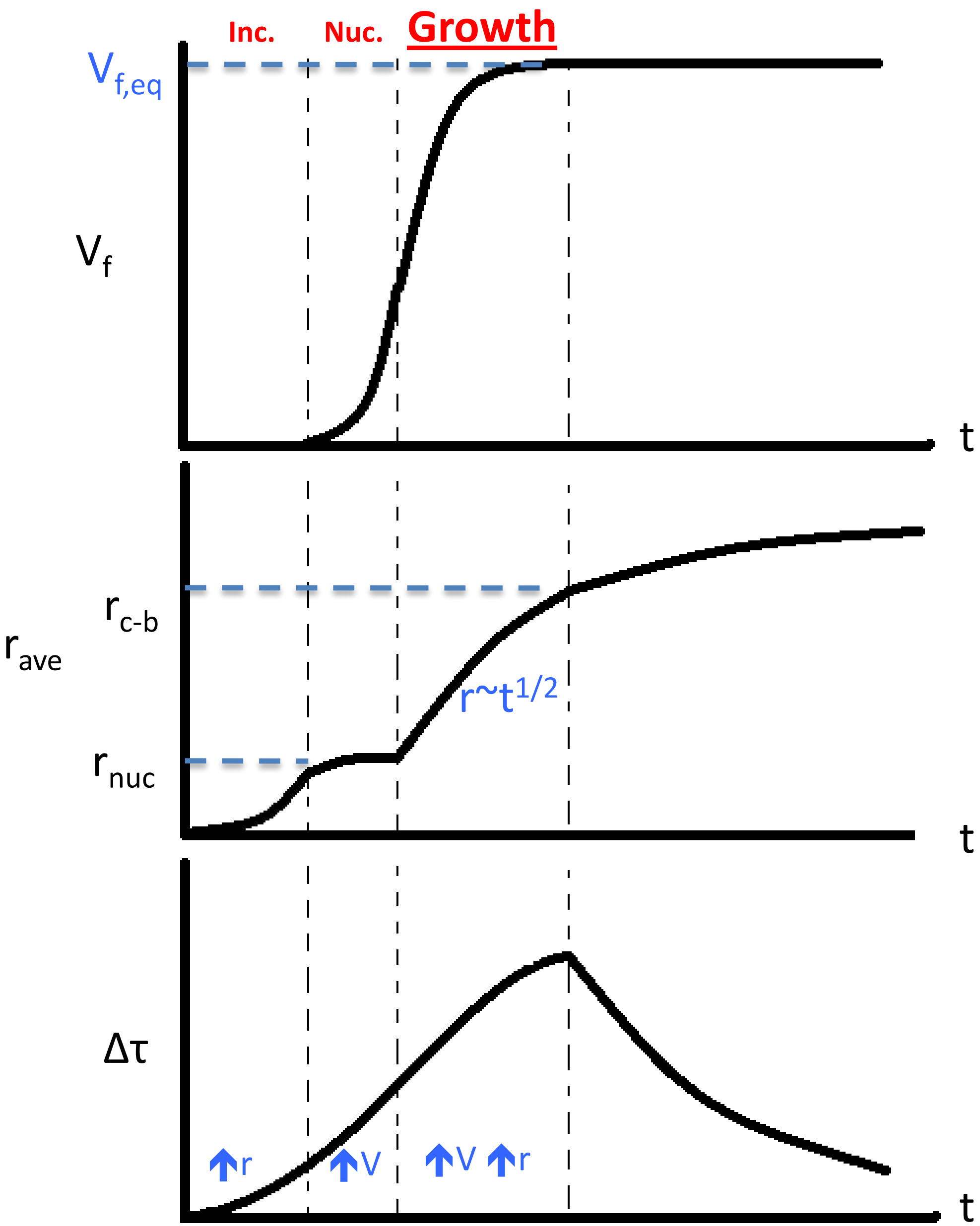
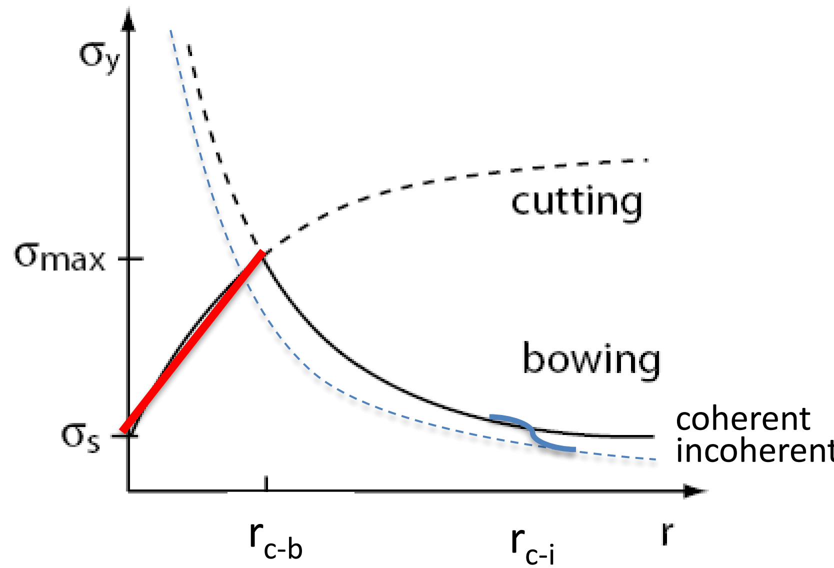
Precipitation Hardening: Kinetics





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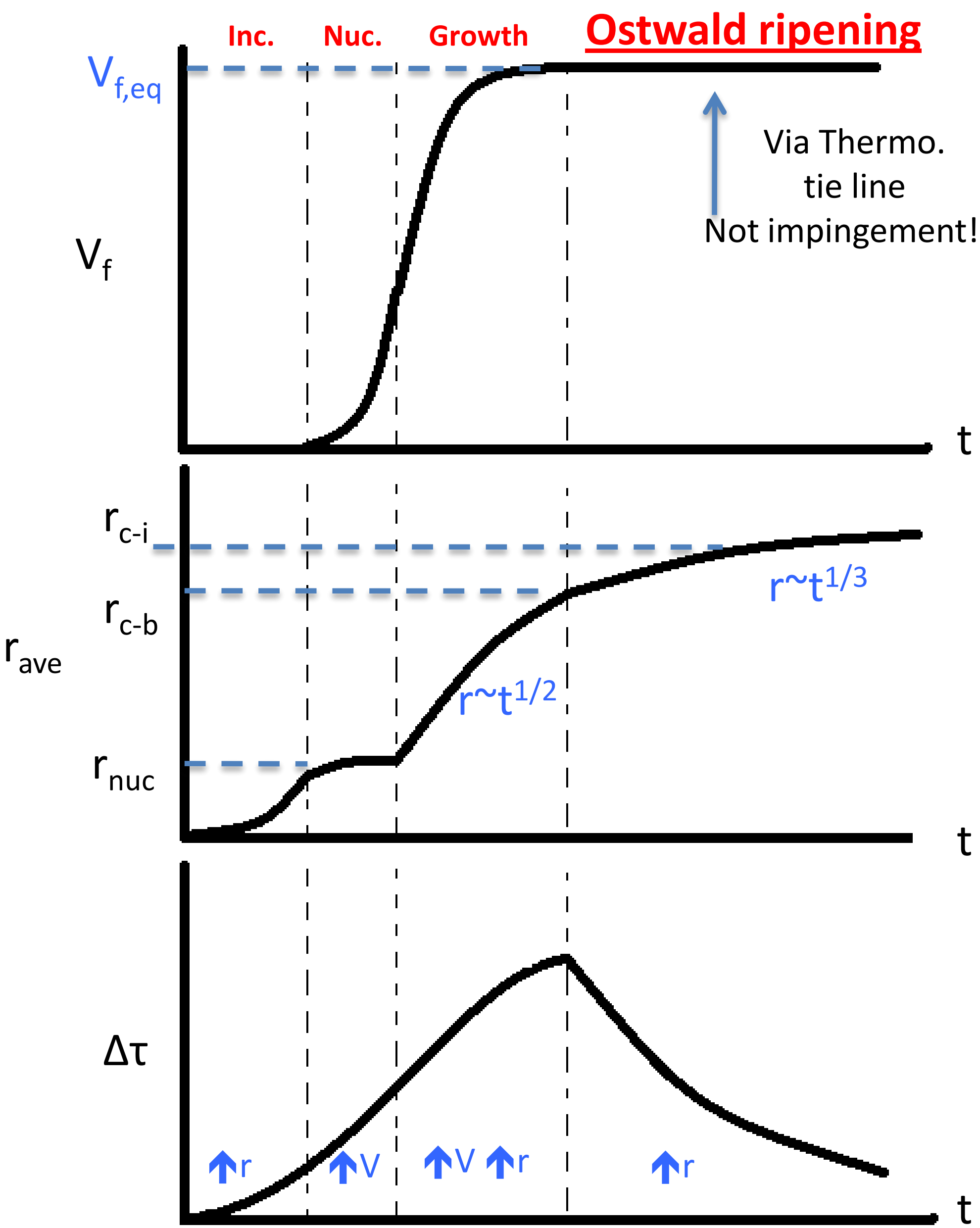
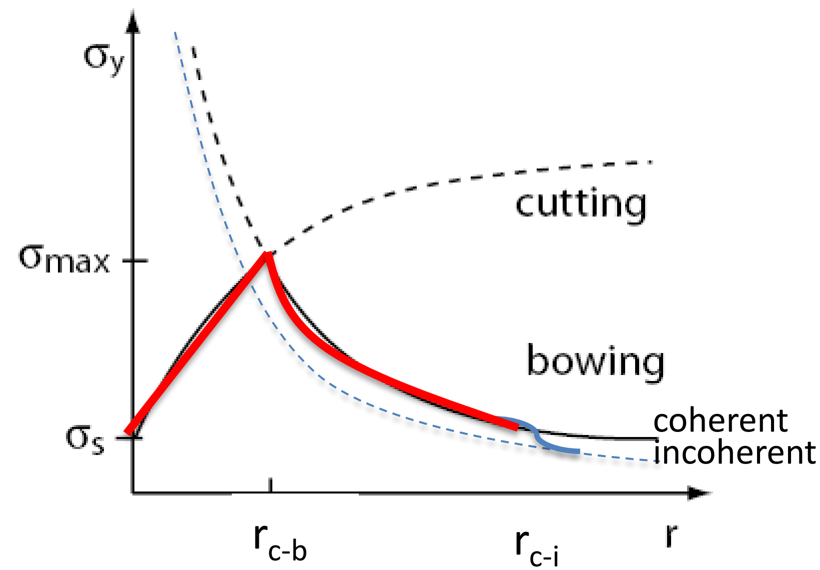
Large contribution to strengthening:
Volume fraction and radius increasing

Precipitation Hardening: Kinetics





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Sweet Spot for Max Strengthening:

r_{c-b} & $V_{f,,eq}$

Gibbs-Thompson Effect: Ostwald ripening

Curvature affects free energy diagram → ↑ solubility in smaller particles
Established concentration gradient → Large grow, small shrink

R. Balluffi, S. Allen, C. Carter. Kinetics of Materials. Hoboken, NJ: J. Wiley & sons. 2005   W. Hosford. Physical Metallurgy CRC Press, 2005

Time-Temperature-Transformation Diagram (TTT)

Plots representing the level of transformation (in %) during an isothermal process from non-equilibrium conditions to equilibrium vs. time

TTT diagram

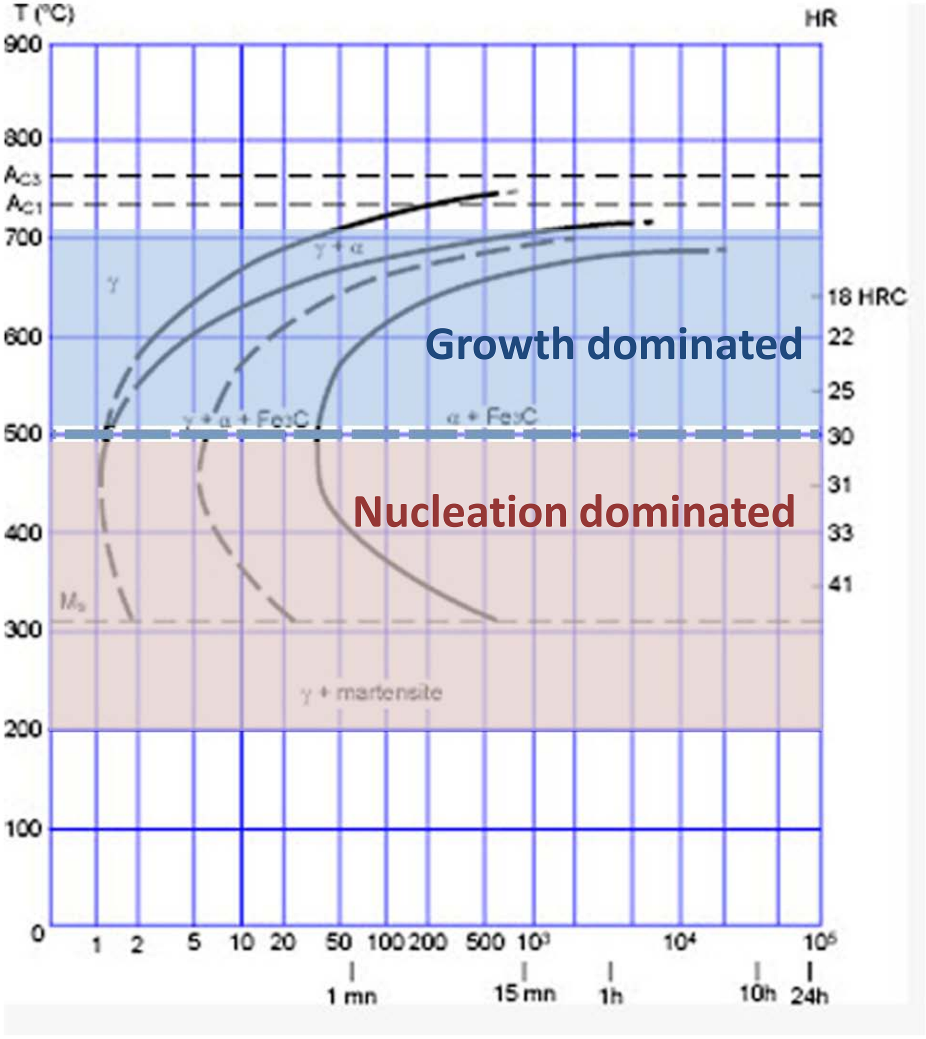
Please see "Underlying Metallurgy: Transformation Diagrams (CCT & TTT)." *SteelMATTER*. University of Liverpool, 2000.

Shape of the TTT diagram

- Existence of a nose: competing mechanism
- High T favorable to diffusion > growth dominated
- Low T favors nucleation as the driving force (difference in free energy G) is large

TTT diagram has a nose separating growth dominated from nucleation dominated regions

TTT continued



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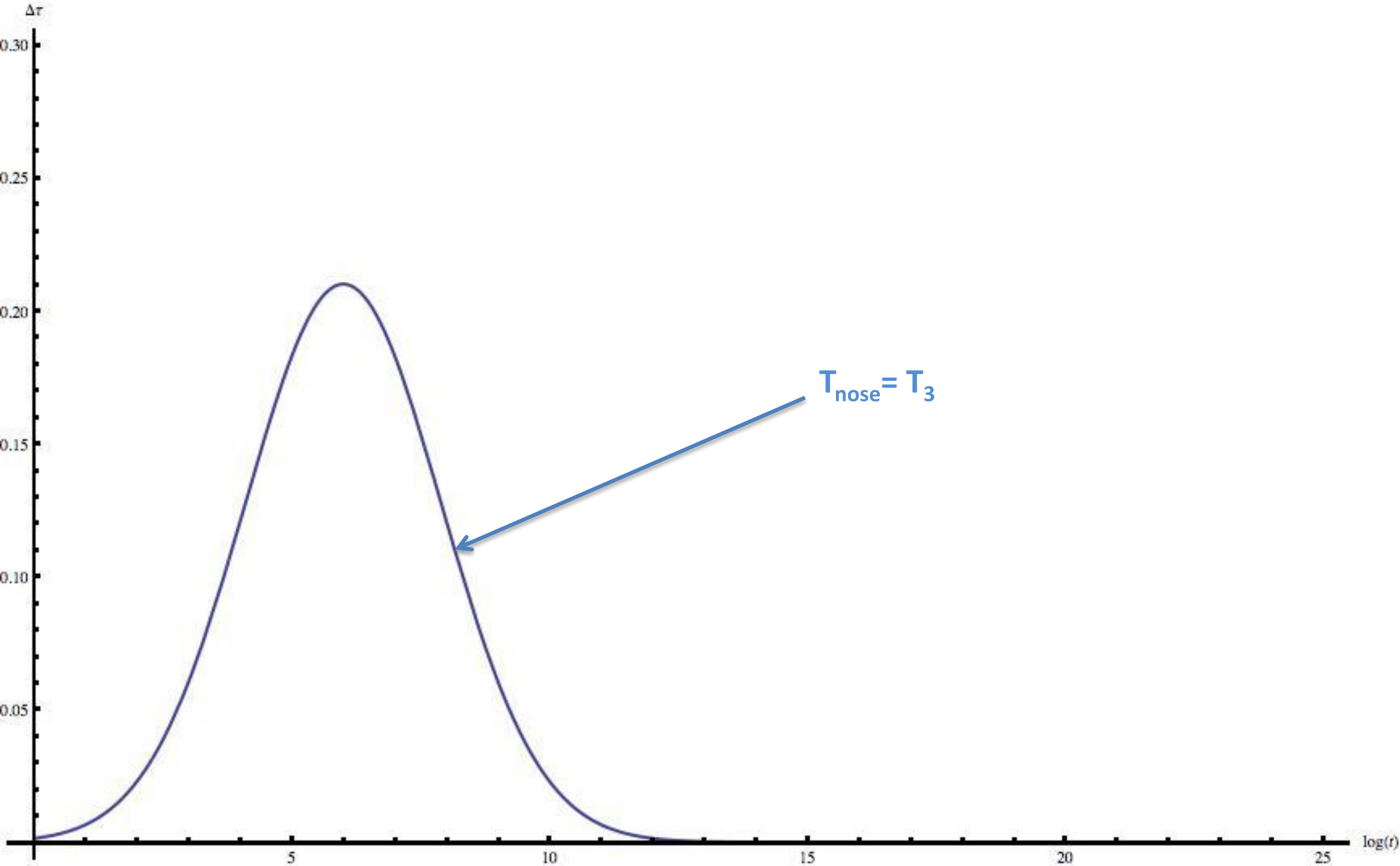
How does strength evolves with time at constant T?

1) Bell-shape curve
2) Fastest at T_{nose}

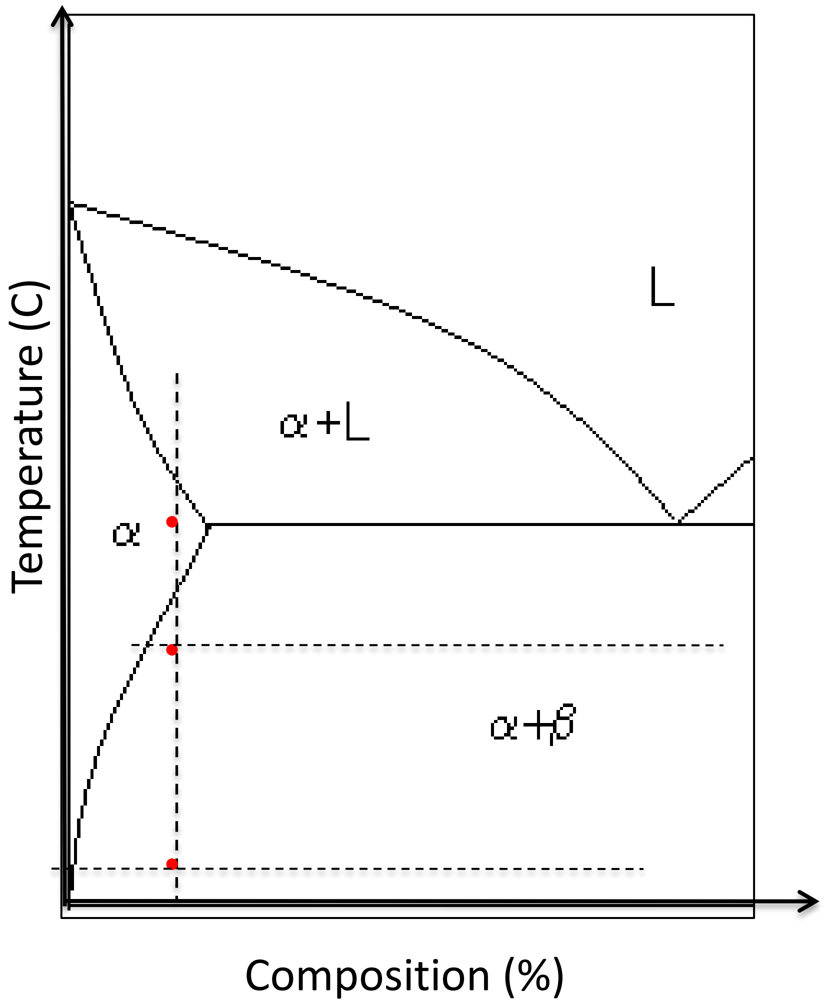
Strength vs. time



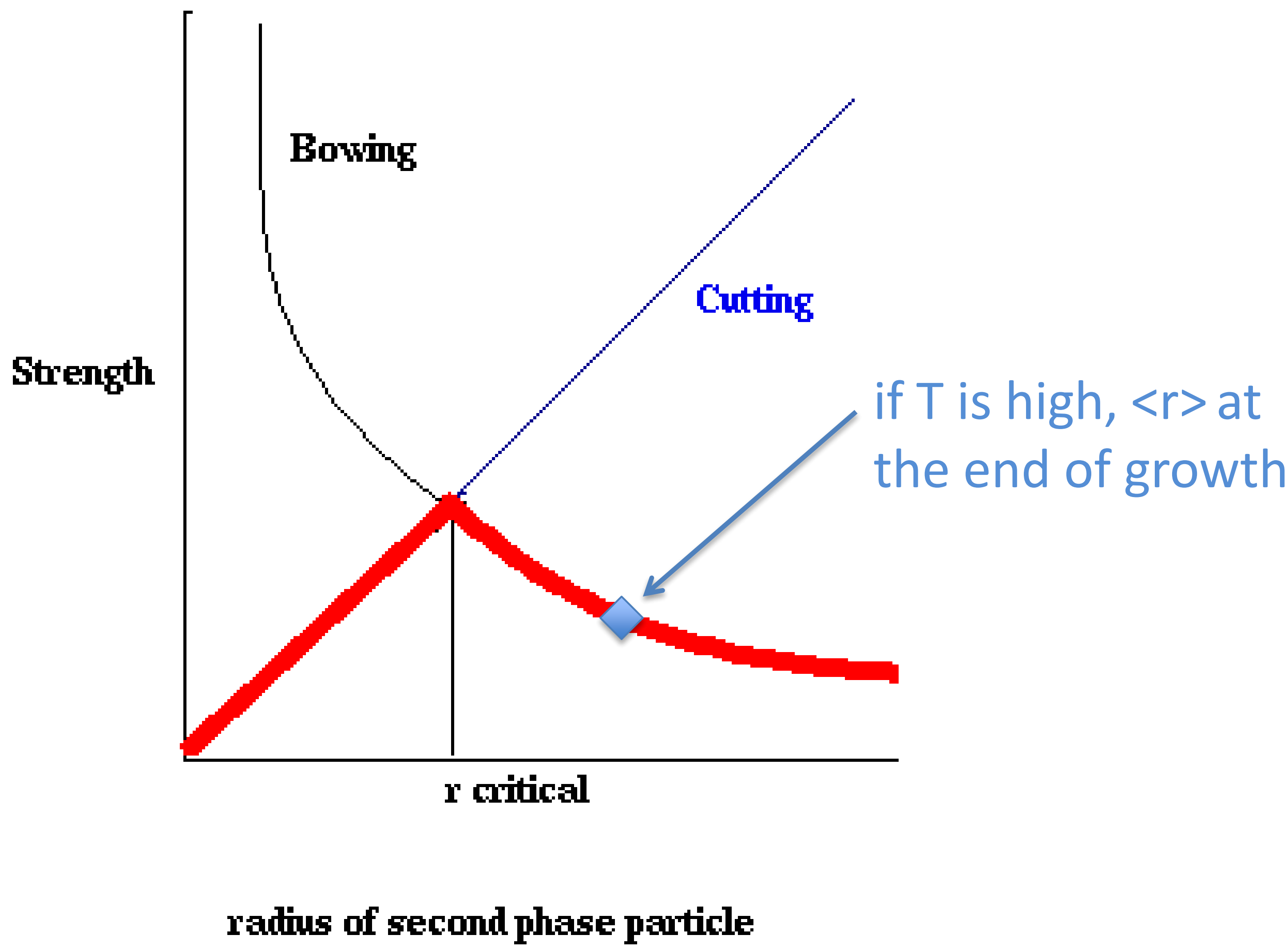
How does strength evolves with time at constant T?

1) Bell-shape curve
2) Fastest at T_{nose}
3) If T is high, V_f is getting smaller (lever rule) > few precipitates + before coarsening $\langle r \rangle > r_{c/b}$

Phase Diagram

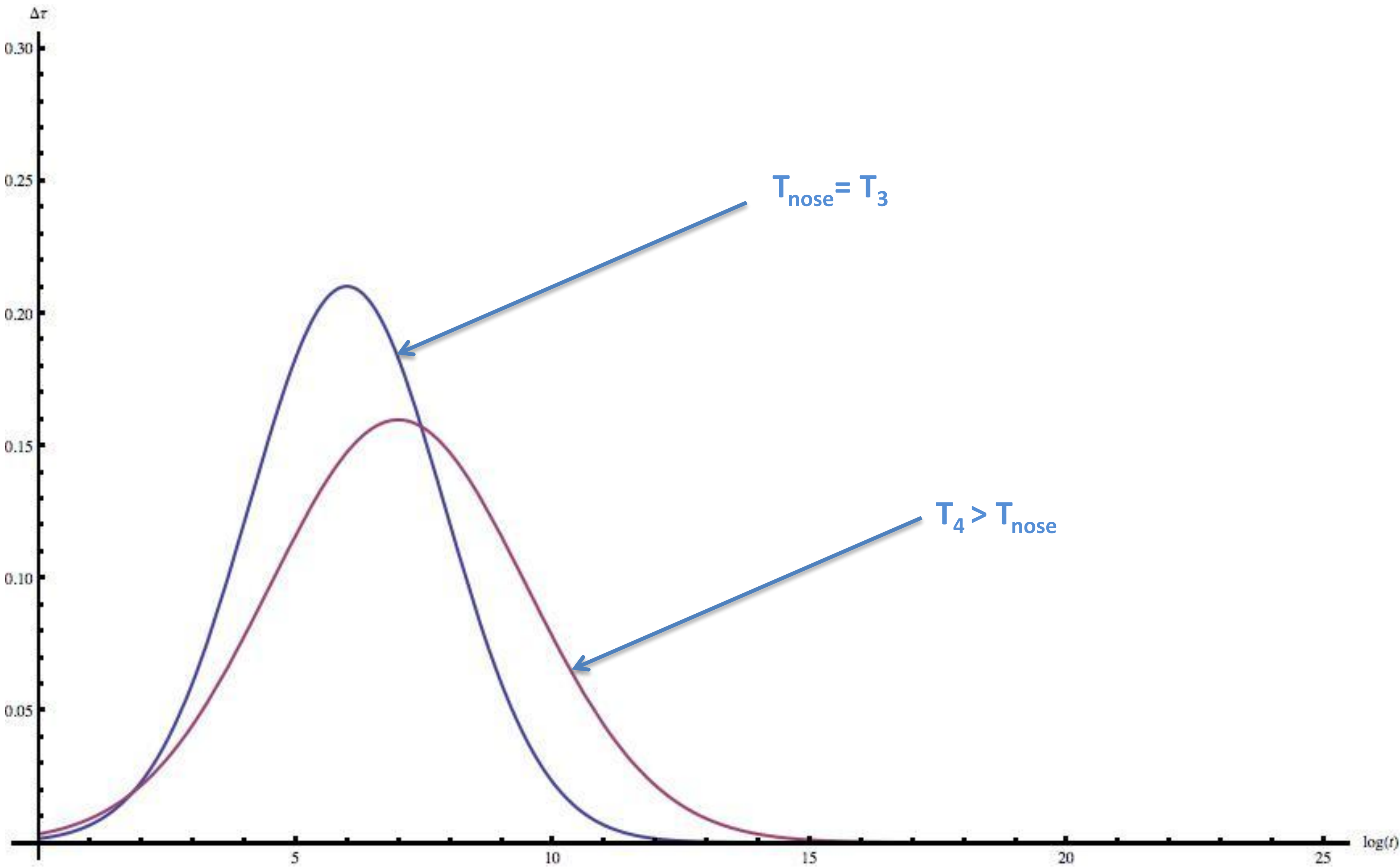


http://www.doitpoms.ac.uk/tlplib/phase-diagrams/lever.php



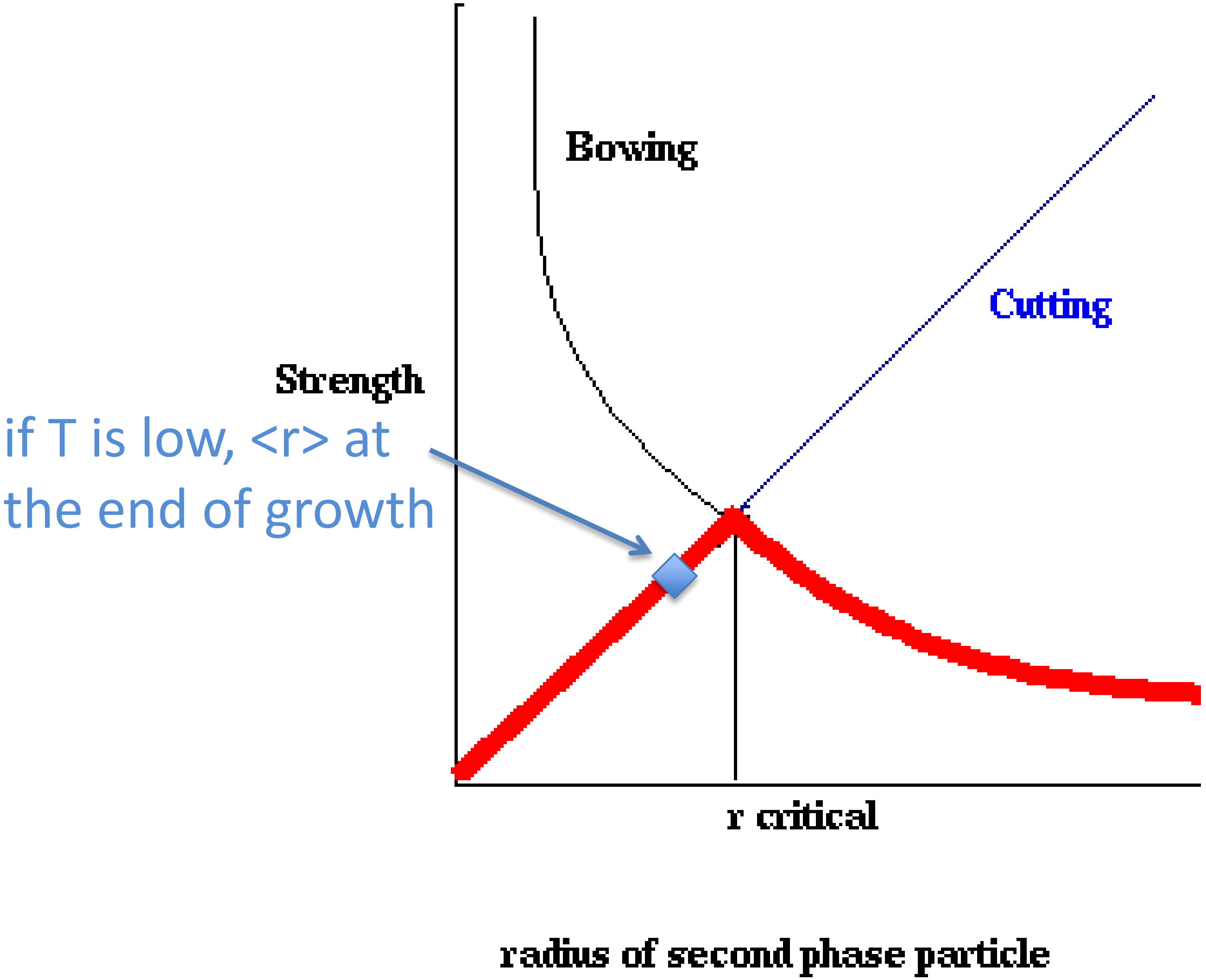
http://upload.wikimedia.org/wikipedia/en/6/63/Strengtheningg.png

Strength vs. time



How does strength evolves with time at constant T?

1) Bell-shape curve
2) Fastest at T_{nose}
3) If T is high, V_f is getting smaller (lever rule) > few grain + before coarsening $<r> > r_{c/b}$
4) If T is low, nucleation is dominating, lots of small grain: $<r> < r_{c/b}$



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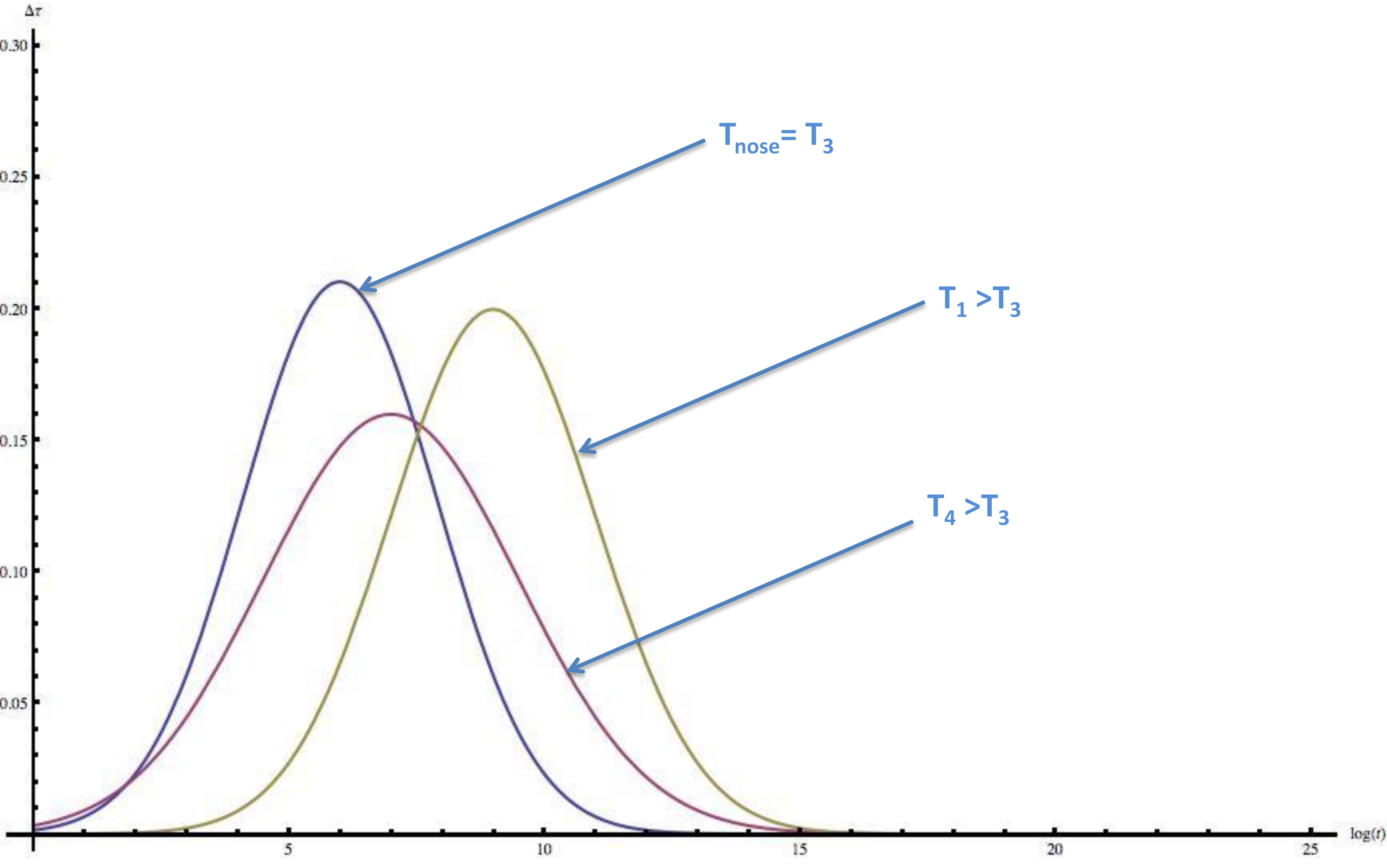
Strength vs. time



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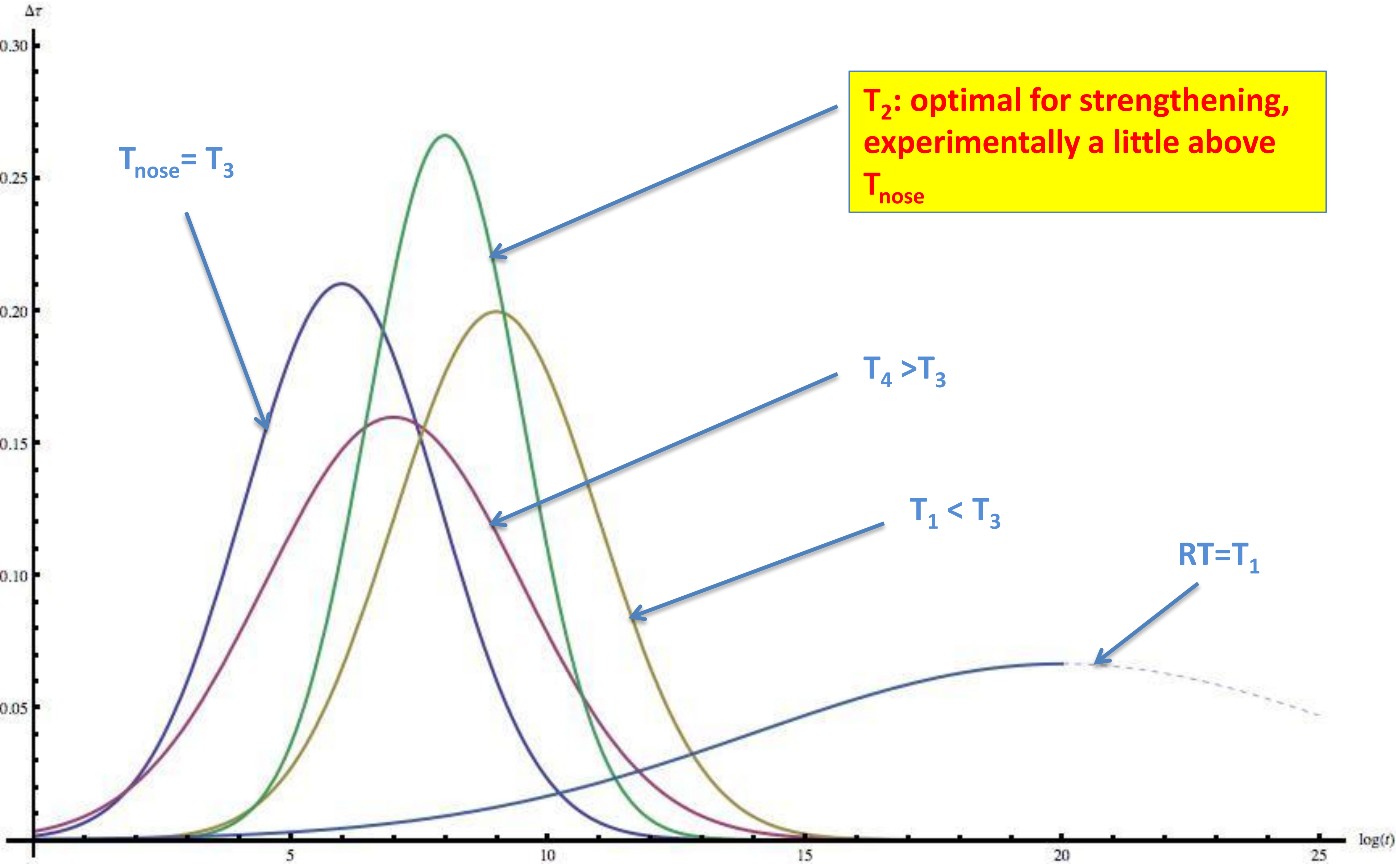
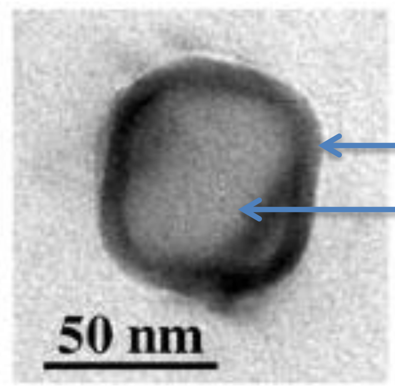
There is an optimal temperature for maximum strengthening at $\langle r \rangle = r_{c/b}$

Strength vs. time



Refinements

- Take into account aging during service
- Non metallic precipitates e.g. VC in Fe-V-C
- Core-shell e.g. Zr around Al_3Sc



- Particle alignment (coherency stress) e.g. Ni_3Al in Ni-Al
- Extrinsic nanoparticles seeding > no growth, no shear

3.40J / 22.71J / 3.14 Physical Metallurgy
Fall 2009