

# Transitional course for PhD students

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Why do we need  
a transitional course?

# Who is a PhD student?

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aspirant

ə'spɪr(ə)nt, 'asp(ɪ)r-/

*adjective*

adjective: **aspirant**

**1.**

having ambitions to achieve something, typically to follow a particular career.

*noun*

noun: **aspirant**; plural noun: **aspirants**

**2.**

a person who has ambitions to achieve something.

# What is the problem?

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- PhD (postgraduate) studies as separate from BSc and MSc
- PhD studies are in fact, mostly, research projects linked to specific grants
- PhD students in many countries are not really students but researchers
  
- Specifics of a PhD research may require skills not available in the university
- PhD applicants maybe have different educational or research background
- PhD application maybe from different country where the contents/focus of education is different

# Who is a solution?

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Introduce a PhD student to a new field/subject and supply **practical and useful information** that can be absorbed **using only basic knowledge** and will **allow** a PhD student to learn deeper and wider by him/herself

# Aims of the module

The main emphasis is on **supplying** PhD students from various BSc/MSc backgrounds **with essential knowledge** on materials science and processing that is required for successful pursuing of PhD project in the areas of materials science, metallurgy and materials processing. The module creates the background that **allows** PhD students to **further develop and deepen their knowledge** and **enhance the quality of analysis** of their research outcome. Other than materials science transitional modules maybe developed based on the same approach



# Learning outcomes

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The module provides opportunities for PhD students to **develop and demonstrate knowledge and understanding, qualities, skills** and other attributes in the following areas:

- Main relationships governing phase transformations in condensed systems.
- Principles and types of phase diagrams and learn to apply phase diagrams to the analysis of metallic alloy processing.
- Phenomena of nucleation and growth and controlling parameters.
- Controlling parameters of structure formation in metallic alloys.
- Metal processing routes, from solidification to deformation and heat treatment.
- Basics of data analysis and scientific writing.

# Learning outcomes

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**At the end of the course, participants are expected:**

- **To understand the laws of thermodynamics**, descriptions of thermodynamic systems and the basic thermodynamics and kinetics of nucleation and growth in solidification;
- **To understand principles and mechanisms governing the formation of characteristic solidification microstructures** and the importance of grain refinement;
- **To be familiar with various casting technologies** and appreciate both strong and weak points of individual casting processes;
- **To apply the above knowledge to the analysis** of the solidification process of a given alloy, predict solidification structure, and identify and solve practical problems, particularly in the context of microstructural control in their own research.
- **To become familiar with the current solidification science and practices** within the archival literature.

# Contents

## **1. Basics of thermodynamics and kinetics in solidification. (2 hrs)**

- Introduction to phase transformation and solidification.
- Basics of thermodynamics and kinetics in solidification.
- Driving force for solidification.
- Brief review of classical nucleation theory (homogeneous and heterogeneous nucleation).
- Free growth model.



# Contents

## 2. Phase diagrams. (2 hrs)

- Free energy and Gibbs phase rule.
- Binary phase diagrams: principles.
- Typical mistakes on phase diagrams
- Types of solidification and solid-state reactions.
- Cooling curves and phase transformations.
- Examples of practically important phase diagrams and their analysis.



# Contents

## **3. Equilibrium and non-equilibrium solidification. (2 hrs)**

- Lever rule and Scheil approximation.
- Solute segregation and microsegregation. Constitutional undercooling.
- Effects of nonequilibrium solidification.
- Metastable and nonequilibrium phases.



# Contents

## 4. Microstructure evolution during solidification. (2 hrs)

- Crystal growth mechanisms.
- Main growth morphologies: faceted and nonfaceted.
- Main growth types: equiaxed and columnar, columnar-equiaxed transition.
- Stability of Interfaces and dendritic growth.
- Eutectic and peritectic structures.
- Controlling factors of microstructure evolution: cooling rate, thermal gradient.



# Contents

## 5. Nucleation and grain refinement. (2 hrs)

- Classical nucleation theory.
- Homogeneous and heterogeneous nucleation.
- Nucleation criteria for good substrate.
- Grain refining practice.
- Current views on the nature of grain refinement in metallic alloys.
- Eutectic modification.
- Importance of grain refining and eutectic modification in alloy performance.
- Application of the same principles to solid-state precipitation.



# Contents

## **6. Structure formation in castings and its control. (2 hrs)**

- Grain size, dendrite arm spacing, eutectic colony.
- Grain refinement
- Thermal and solutal convection.
- Dendrite fragmentation and coarsening.
- Special morphologies.
- Transition region in solidification, slurry and mushy zones, permeability.
- Structure zones and control in castings.



# Contents

## 7. Casting defects. (2hrs)

- Processes during solidification.
- Shrinkage, gas, porosity.
- Control of porosity: modern technology.
- Macrosegregation: mechanisms.
- Control of macrosegregation: from structure to process parameters.
- Hot tears: mechanisms and challenges.
- Control of hot cracking: from structure to process parameters.
- Cold cracks: mechanisms and challenges.
- Control of hot cracking: from structure to process parameters.



# Contents

## 8. Modern casting technologies. (2 hrs)

- Types of casting products: final and semi-finished items.
- Continuous processes: direct-chill and continuous casting; twin-roll casting.
- Shape casting: investment and die casting, low- and high-pressure die casting.
- Post-casting treatment: stress relief, homogenisation, cleaning.



# Contents

## **9. Strengthening mechanisms and thermo-mechanical treatment. (2 hrs)**

- Hardening mechanisms: precipitation, phase re-crystallization, martensite.
- Deformation and recrystallization.
- Heat treatment of light alloys.
- Heat treatment of steels.



# Contents

## **10. Data analysis. (1 hr)**

- Sample preparation and microscopic analysis.
- Mechanical testing: hardness, tensile testing.
- Statistical analysis of results.



# Contents

## **11. Scientific writing. (1 hr)**

- Journal choice (citation metrics)
- Basics of a good scientific paper.
- Review process.



# Literature/course material

## 1 ESSENTIAL READING [\* Purchase advised] (subject specific)

- \*I.I. Novikov et al., Metals Science, vol. 1 and 2, Moscow, MISiS, 2009 (in Russian).
- or
- \*I.I. Novikov, Theory of Heat Treatment of Metals, Moscow, Metallurgiya, 1986 (or other edns.) (in Russian).
- \*W. Kurz, D.K. Fisher, Fundamentals of Solidification, 4<sup>th</sup> Edn, Transtec Publ., 2005.
- J. Campbell, Complete Casting Handbook. Metal Castings Processes, Techniques and Design, Oxford, Butterworth-Heinemann, 2011.

## 2 RECOMMENDED READING (subject specific)

- \*N.A. Belov, D.G. Eskin, A.A. Aksenov. Multicomponent Phase Diagrams. Applications for Aluminum Alloys, Amsterdam, Elsevier, 2005.
- \*D.G. Eskin. Physical Metallurgy of Direct Chill Casting of Aluminum Alloys, Boca Raton, CRC Press, 2008.

## 3. OTHER (advanced reading; subject specific)

- \*J.A. Dantzig, M. Rappaz. Solidification, Lausanne, EPFL/CRC Press, 2009
  - K.F. Kelton, A.L. Greer. Nucleation in Condensed Matter. Applications in Materials and Biology, Oxford, Pergamon, 2010.
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