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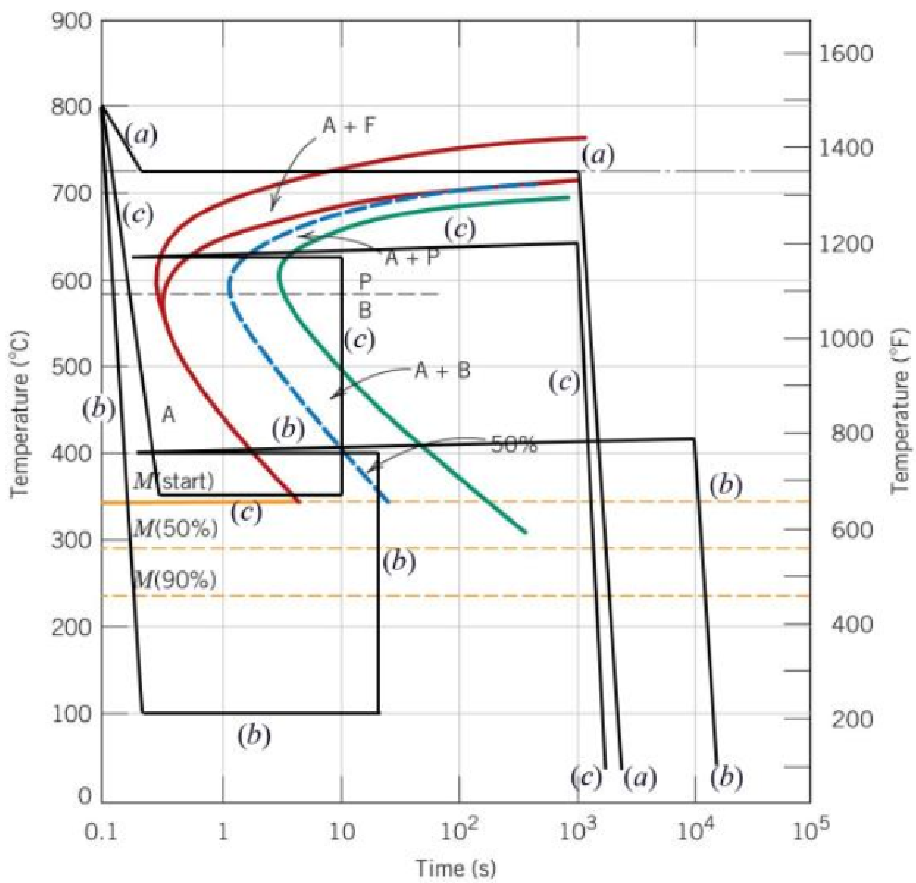
Task 1. Phase Transformation (15 points, Lecture 9)

The following figure is the isothermal transformation diagram for a 0.45 wt% C iron-carbon alloy. List the microconstituent(s) present for the heat treatment labeled (a-c) on this diagram. Please explain your results.



[Reference: W. D. Callister and D. G. Rethwisch, Materials Science and Engineering: An Introduction, 8th Edition, Wiley, 2009.]

a) cool down to around 725°C within first second, keep temperature for 10^3 seconds, some austenite will transform into proeutectoid ferrite. Then it is cooled rapidly to room temperature, turning the rest austenite into martensite.

=> final microconstituents present for the heat treatment (a) are proeutectoid ferrite and martensite (answer)

b) rapidly cool down to 100°C within first second, hold for around 30 seconds, then rapidly heat up to 400°C. All of the austenite is transformed into martensite. Restarting time count, heat up very little for a long time around 10^4 seconds. The martensite is tempered, becomes tempered martensite, then rapidly cool down

=> final microconstituent present for the heat treatment (b) is 100% tempered martensite (answer)
c) rapidly cool down to around 350°C within first second, hold for around 10 seconds. Some of the autensite is transformed into bainite. Then rapidly heat up to around 625°C. Restarting time count, heat up very little for a long time around 10^3 seconds. Some austensite is transformed into proeutectoid ferrite first and then some of the austensite continues to transform into pearlite. At the end of this long heating process, all of the martensite left is transformed into pearlite. Finally, the material is rapidly cool down
=> final microconstituent present for the heat treatment (c) is bainite, proeutectoid ferrite and pearlite (answer)

Task 2. Process (52 points, Lecture 9)

2.1 Explain what casting is? List at least four types of casting methods with their frequently used mold materials, general process, and applications. And make a comparison between different types of casting methods, using either tables or plots. (Hint: you can explain with methods, usages, results, examples, etc.)

- Definition: Casting is a process of melting materials such as metal and plastic into a liquid form, and then pouring it into a premade mold with a hollow cavity of a desired shape. The liquid is left to solidify in the mold, creating a solid with the desired shape.
- Four types of casting methods

1) Sand casting
+ Mold materials: sand casting use sand as the mold materials
+ General process: create a patterned shape, then pack sands around the shape mold. Usually there are air vents and a riser to check if the liquid metal has completely filled the mold in the casting process
+ Applications: sand casting can be used to produce pistols and valves, impellers, gas/oil tanks, screws, nuts and gears, car parts and engine blocks

2) Investment casting
+ Mold materials: investment casting uses refractory materials (commonly wax and plaster) for molds
+ General process: the first stage of the process is to produce an exact replica of the required casting made of wax. Plaster is then poured into a die surrounding the wax model and solidifies. Then the wax is melted, turning the plaster into a hollow mold. After that, liquid metal is poured into this mold in the casting process. It is called investment casting because the process has to invests in the replica with refractory material (wax, plaster, ceramics, etc) to make a mould
+ Applications: investment casting can be used to produce rotors, turbine blades, generators, casings, pistons and other engineering components

3) Die casting
+ Mold materials: The dies forming the mold is usually made from non-ferrous metals, such as zinc, magnesium, aluminium and tin-based alloys

+ General process: the mold is predefined by two hardened dies which will form a mold casting when the dies are attached together. The liquid metal will be pushed to fill the complex casting design inside the mold by high pressure. After filling the whole cavity, the two hardened dies are detached, revealing the solidified liquid metal.
+ Applications: die casting is used for construction like building frames, roof infrastructure; in electronic components that are heat resistant; in energy sector like drilling machinery, valves, flow controls and impellers

4) Continuous casting

+ Mold materials: the mold for continuous casting is mostly made from graphite or copper
+ General process: Liquid metal is first poured from the ladle into a tundish. The tundish has a constant output cross section for molten steel to flow into the mold via a submerged entry nozzle. As the steel is poured from the tundish to the mold, it solidifies to form a thin bar, strand or slab and then continue to roll on the curving rollers and cooled down by water spray
+ Applications: continuous casting does not focus on finished design, but it manufactures semi-finished products such as bars, slabs, strands and tubes made from steel and non-ferrous metals for further processing

- Comparison between different types of casting methods

	Sand casting	Investment casting	Die casting	Continuous casting
when to use the casting technique	- need low cost production - casting of all sizes and weights; easy to scale - can be used for majority of metals	- high dimensional accuracy - reproduction of fine detail - high quality finish	- casting small parts - low melting point metals and alloys for casting - intricate design	- needs semi finished metal products for further processing. - low cost production
automation	Can be automated with sand molding machine	The process requires many steps, not easily automated	Highly automated	Highly automated
result	Nearly all metals can be cast with sand casting technique	A wide variety of metal products with high precision	Pressurized cast of low melting point, non ferrous metals	Semi finished cooled strands, bars, slabs or tubes metals

2.2 Explain annealing and its various types of applications. Compare the differences between full annealing with quenching and tempering in terms of processing parameters, resulting microstructure, and mechanical properties.

- Definition: Annealing is a heat treatment process which changes the microstructure of a material, altering physical and chemical properties of the material. Annealing involves heating a material above its recrystallization temperature at a constant temperature for a definite time, then the material is cooled down back again

- The differences between full annealing with quenching and tempering

	Full annealing	Quenching	Tempering
Processing parameters	- T_{anneal} is the critical temperature needed to reheat the metals above it to get austenite. Then slowly cooling the material down - There is transformation phases throughout the process	- Reduce the high temperature rapidly down to room temperature, resulting in supercooling of the material - There is transformation phases throughout the process	Heating the quenched martensite up to the temperature below its melting point then slowly cooled down in normal air - There is no complete phase transformation.
Resulting micro structure	coarse pearlite, with proeutectoid ferrite	martensite	tempered martensite
Mechanical properties	Reduce the material hardness and increases its ductility to become more workable	Resulting martensite is very brittle with high strength, not workable in real life applications	Makes martensite in quenching process more ductile without compromising the material strength

Task 3. Inorganic Non-metallic Materials (33 points, Lecture 10)

3.1 True or False

(1) For noncrystalline ceramics, plastic deformation occurs by the motion of dislocations.

=> **False**: Plastic deformation occurs by diffusion

(2) The coordination number of ionic ceramics is constrained by the relative sizes of the compound's component species.

=> **True**

(3) Consider the ZrO_2 crystal structure. The coordination number of Zr^{4+} ions is 8

=> **True**

(4) Na_2O, CaO, Al_2O_3, and B_2O_3 are all oxides that may be found in silica-based glasses.

=> **True**

(5) With increasing temperature, the following is the correct phase transformation sequence for a glass: supercooled liquid, solid, and liquid.

=> **False**: correct sequence is solid, supercooled liquid and liquid

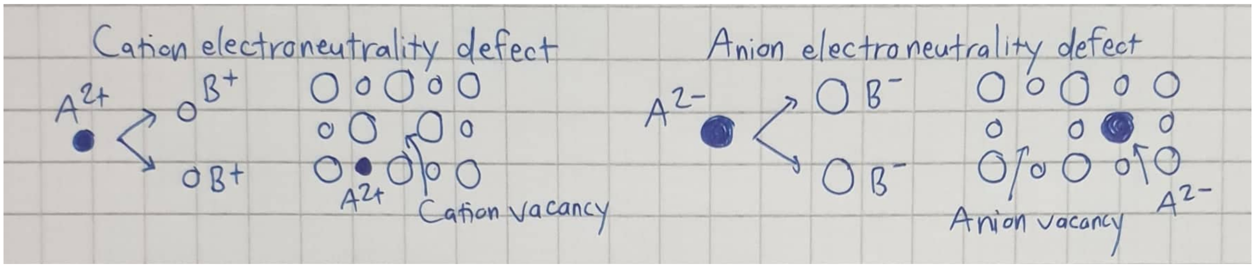
(6) Consider the ideal barium titanate ($BaTiO_3$) structure, the coordination number of the Ba^{2+} ion in terms of surrounding Ti^{4+} ions is 8.

=> **True**

3.2 Name and plot seven kinds of ionic point defects that are found in ceramic compounds. (Please use figures and illustrations and make a proper citation of the figures if they are not created by you.)

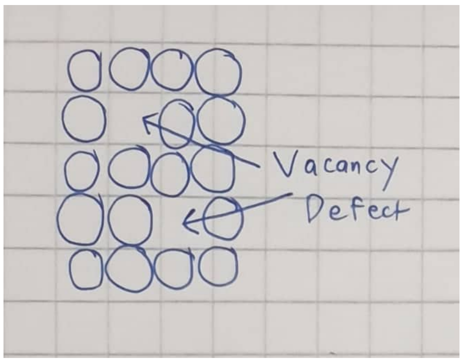
Seven kinds of ionic point defects found in ceramic compounds are:

1) Maintenance of charge neutrality

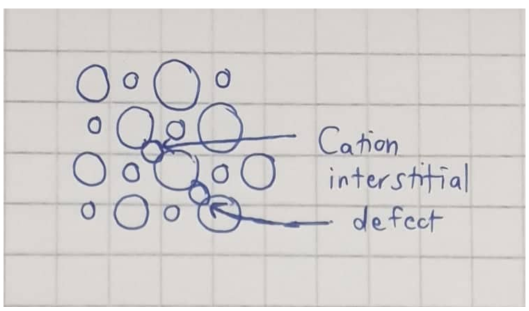


- Atomic point:

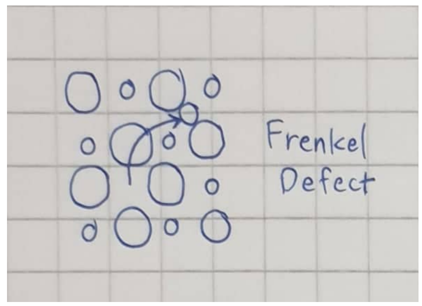
2) Vacancy



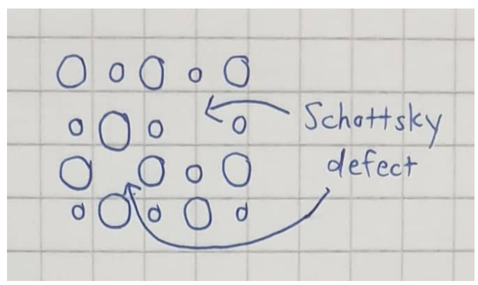
3) Interstitial (cation)



4) Frenkel

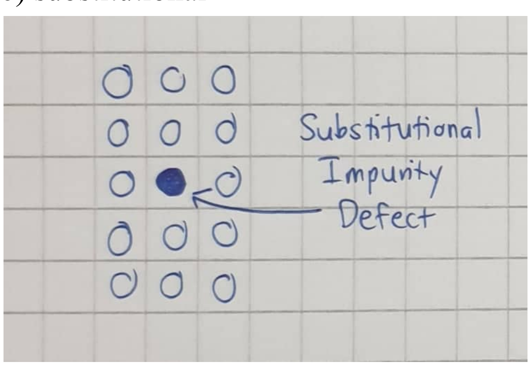


5) Schottky



- Impurities:

6) substitutional



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