8 Metals as Biomaterial

8.1 Subdivide metallic implants with respect to the usage period, give typical applications and defined the most important properties (why metals?). Summarize the use of metals as biomaterials (stainless steel, CoCr-alloys, Ti-based alloys, noble metal alloys) discussing both structural and surface biocompatibility

- **Temporary implants**

  Surgical devices/equipment - ultra-short
  Bone fixation (screws, plates, wires, nails, etc.)

- **Permanent implants**

  Joint implants (hip, knee, shoulder, etc.)
  Teeth
  Spine
  Stents

- **Surface Biocompatibility** Adaptation of the chemical, physical, biological and morpholigical surface properties of the implant to the needs of the surrounding tissue aiming at the clinically desired interaction and make sure that the nature accept it. Following question have to be answerd :

  – How strong is the metal alloy?
  – How much defornation has to be expected for a given load?

  This questions can be answered by tensile and compression and cuclic loading behaviour which is Fatigue strength [MPa], young modulus, thermal expansion and melting point, hardness and stiffness. With regard to this characterization we can understand that:

  – Metals have close packed structure.
  – Metals are inorganic and crystalline.
  – Atoms bond through metallic bonding.
  – Strong and easily form in to complex shape.
  – Biocompatibility.

  That is the reason for using metallic implants.

- **Structural biocompatibility**
  Adaptation of the implant structure to the mechanical behavior of the surrounding tissue (host tissue). This includes the design (macroscopic shape) as well as the inner structure (i.e. anisotropic porous structures, placement of fibers in anisotropic materials). Goal is mimicry of structure.(structure need to be imitated, replaced),(biomechanis need to fullfield) Also we should consider replace nature and surface biocompatibility, Adaptation of the chemical, physical, biological, and morphological surface properties of the implant to the (needs) of the (goal) surrounding tissue aiming at a clinical desired interaction.

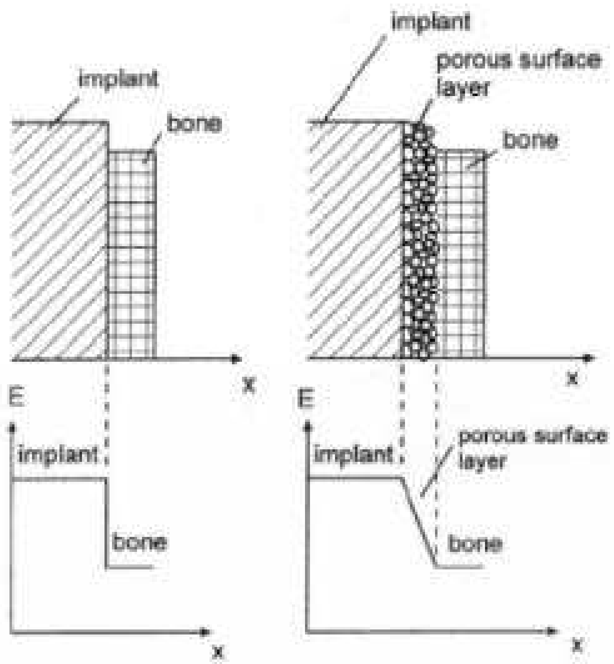
8.2 The interactions of the biosystem with the metallic implant should be listed. What are the main physicochemical parameters characterizing the surface properties, which finally determine the response of the tissue to the metallic implant? Please find out the meaning of the Vroman effect.

- Surface of the bulk material
- Oxidation of the surface
- Water adsorption
- Ion release
- Protein adsorption
- Cell attachment
- Tissue formation

The **Vroman effect** describes the protein adsorption at implant surfaces. The smaller proteins are faster and will therefore reach the surface first. They will become replaced by the larger, less mobile species, which form a stronger load to the substrate.

8.3 What is the goal of tailoring the stiffness of a load-baring metallic implant to the biological environment? How this goal is reached?

The goal is to adapt the stiffness of the implant to the stiffness of the surrounding bone. This can be reached by designning the implant's cross section and its Young's modulus.
The Young's modulus E can be intentionally reduced fabricating porous metals. If p denotes the degree of porosity, the following empirical equation is found:
$E_p = E_0(1 - 1.21p^{\frac{2}{3}})$
This equation allows the adaptation of E to the bony tissue.



8.4 Explain the observed phenomena in Shape Memory Alloys?

- Superelasticity
  Superelastic materials can be macroscopically deformed, as soon as the load is removed, the material moves back into its original shape. Deformations up to 8% are reversible.
  Reason for the superelastic material behavior is a martensitic phase transition. The martensitic phase transition is a diffusion-less transi-

tion from the high-temperature phase (austenite) to the low-temperature phase (martensite); the crystalline lattice is not being changed by diffusion of the atoms, instead it becomes distorted by a shearing movement.
To behave superelastic, the material needs to be in austenite state, i.e. its temperature must be higher than the temperature for the phase transformation. If a superelastic material gets deformed, stress-induced martensite is formed prior (i.e. at lower stresses) to "classical" mechanisms of deformation as e.g. sliding. As the martensite is not stable in that temperature range, the crystalline lattice re-transforms back to austenite as soon as the load is removed. As the atoms didn't change their nearest neighbours, the former - austenitic - crystalline lattice is "rebuilt" and the former original shape is recovered.
Superelasticity is used in self-expanding stents for example. Prior to implantation, the stents are shrinked to a smaller diameter and plunged into a tube, which keeps them in the shrinked position. By using the tube, the stent is placed into the desired location. Subsequently, it is pushed out of the tube and - due to superelasticity - expands back into its original shape with a bigger diameter.

- One-way shape memory effect (pseudoplasticity)
  A pseudoplastic material can be plastically deformed, i.e. after removing the load the material stays deformed. After it has been heated above a certain temperature, the material recovers its original shape. Deformations up to 8% are recoverable. Unlike the superelastic material, the pseudoplastic material needs to be in martensite state, i.e. its temperature has to be lower than the temperature for the phase transformation. As the martensite crystalline lattice is sheared, twinning occurs in the microstructure to compensate the elastic strain. Furthermore, many different variants of the martensite can be formed. If the material is deformed, the mechanism on the micro-scale is a de-twinning of the martensite matrix, i.e. some variants of the martensites grow, whereas other, energetically less favourable variants, disappear. The de-twinning occurs at lower strains than the "classical" mechanisms of plastic deformation. If the deformed material is heated to temperatures above the phase transition, i.e. the stable crystalline phase is now austenite, the atoms re-arrange into their former crystalline lattice

and the original macroscopic shape is recovered.
Pseudoplasticity can also be used in self-expanding stents but in this case, the phase transition has to occur below body temperature. Now, the martensitic stents are deformed to smaller diameters. Again the stents are put in tubes, positioned in the human body and pushed out of the tube. As soon as the stents are pushed into the environment of the human body, they are warmed up to body temperature and undergo the phase transition to the austenite state. By doing so, the stents recover their original, wider shape and open the closed vessel.