TFYA21
Physical Metallurgy
Materialvetenskap

Björn Alling
Thin Film Physics Division
Department of physics, chemistry, and biology (IFM)
January-March 2020

Based on course material by Björn Alling, Per Eklund, Lars Hultman

Course schedule

v 5	Må 2020-01-27			
	10:15 - 12:00	TFYA21	P36	Föreläsning
	Fr 2020-01-31			
	15:15 - 17:00	TFYA21	R18	Föreläsning
v 6	Må 2020-02-03			
	10:15 - 12:00	TFYA21	P36	Föreläsning
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Course schedule

v 9	Må 2020-02-24			
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Content of lectures
(note: numbering does not correspond to lecture occasions)

1. Introduction, course information, historical background
2. Thermodynamics of phase stability and phase transformations
3. Theory of Phase diagrams
4. Calculating and constructing Phase Diagrams
5. Diffusion equations, atomic mechanisms
6. Diffusion in alloys
7. Diffusion, concept of moving lattice
8. Microstructure for materials design
9. Point defects, dislocations, stacking faults
10. Solidification - elements
11. Solidification - alloys
12. Diffusional transformations
13. Age hardening
14. Diffusionless transformations
15. Shape memory alloys, amorphous solids, bulk metallic glasses

X. Back-up time, questions about the exam, outlook

Laboratory exercises

1. Metallography - optical microscopy
   Davide Gambino
   Metal Microscope Room M218

2. Fractography - electron microscopy
   Babak Bakhit
   SEM-room inside the clean room lab
   Please change to white coat and put on green shoes. Then wait in the air lock for the lab assistant to pick you up.

3. Phase transformations - Calorimetry
   Smita Rao
   Scanning Calorimeter Lab, Room P211

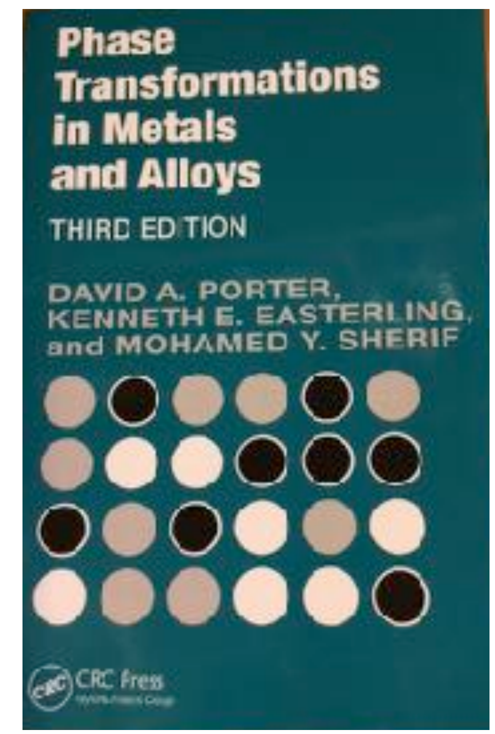
Self-study

- Approximately 116 hours of self studies are recommended
- To support you in this work you have:
  - The course book, including problems and answers.
  - A set of ~80 selected topical problems, the examination will consist of a subset of these problems.
  - Four more complex home assignments that, if correctly solved, gives you bonus-points for the exam
  - Your colleges in the class. Collaborate! (home assignments and the exam should of course be solved individually)
  - Databases of materials properties available on-line and in the library

Course literature

- Main course book: ”Phase Transformations in Metals and Alloys”, David A. Porter, Kenneth E. Easterling, and Mohamed Y. Sherif, CRC Press, Taylor&Francis Group. Third edition.

- This book is practically mandatory for the course.



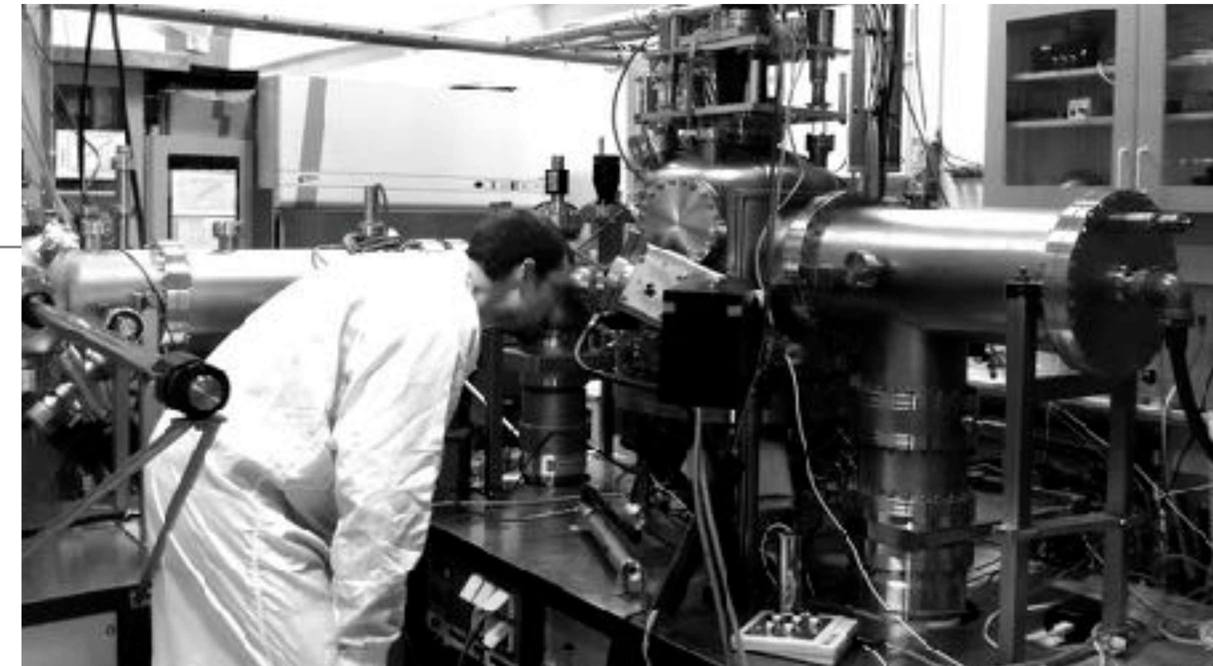
- Compendia for the three laboratory exercises. Digital versions will be provided.

- Book can be bought in the bookstore in Kårallen. If they run out of the book, more can be ordered at ~1 week of delivery time.

Why

Materials Science | Physical Metallurgy?

- We live in a Materials World.
- The properties of materials sets the limits for our utilization of nature.
- It is fun, and you can get a job.








What is Materials Science?

- A historical context is needed to answer this question
- When and were did materials development start? Who was the first to be interested in materials?
- Our own species of man, *Homo Sapiens*, has walked the earth for almost 200 000 years
- Materials development started much earlier

A history of humans and materials

- About 2 millions years ago in an east african rift valley

lived a person of the earliest species of our gender, *Homo*: *Homo Habilis* (handy man).

A history of humans and materials

- Archeologist call her Wilma

Leakey, Tobias, and Napier in 1964

Wilma, as humans of today, lacked sharp teeth or strong claws so a cutting tool must have been highly desirable.

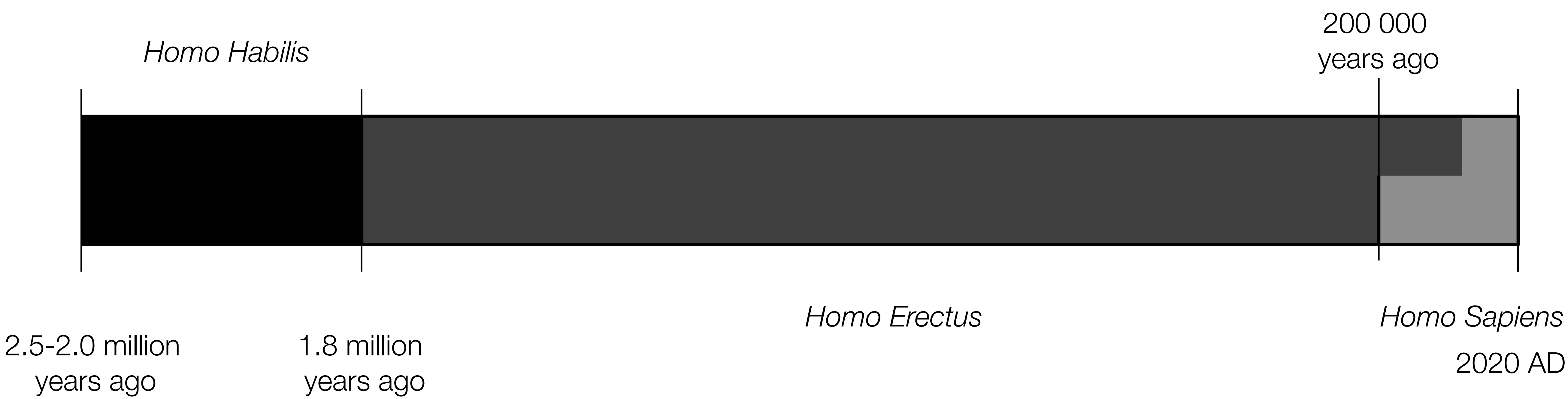
A history of humans and materials

- Pieces of wood, rock, and bone had for sure been used earlier by pre-*Homo* and indeed also other animals as temporal tools in everyday life.

- It was the discovery of the possibility to create sharp stone flakes in *flint,* a particular type of stone, that initiated the so called *stone age* for cutting tools and with it, the human interest in materials structure, properties, and development. Flint is a SiO_2-based nano-composite of different crystal types and domains.

- Obsidian is another type of glassy SiO_2 mineral of volcanic origin used for the same purpose, mainly in the Americas.

A time-line of humans and cutting tool materials



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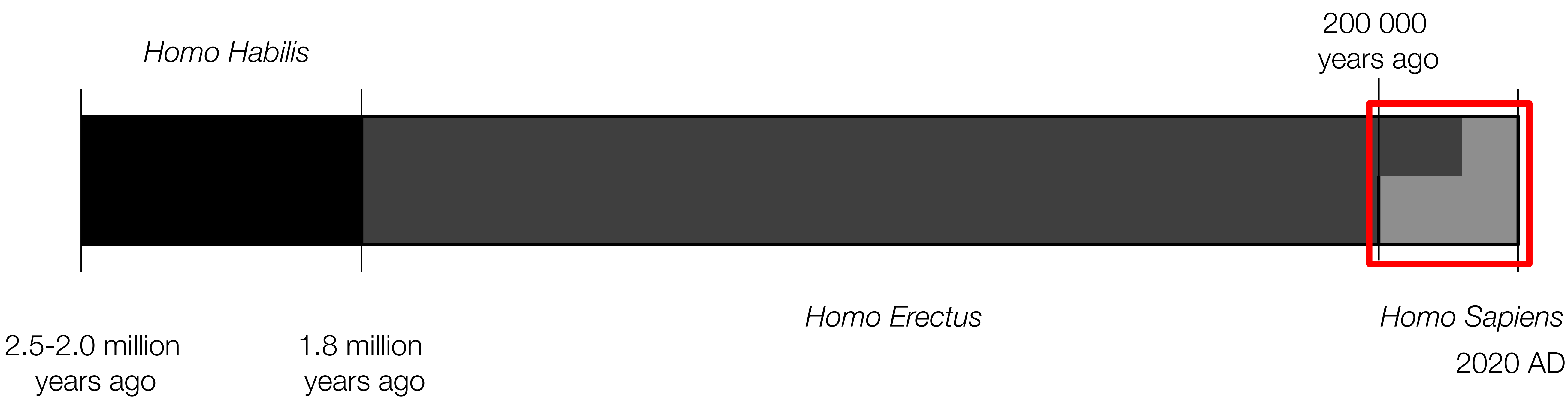


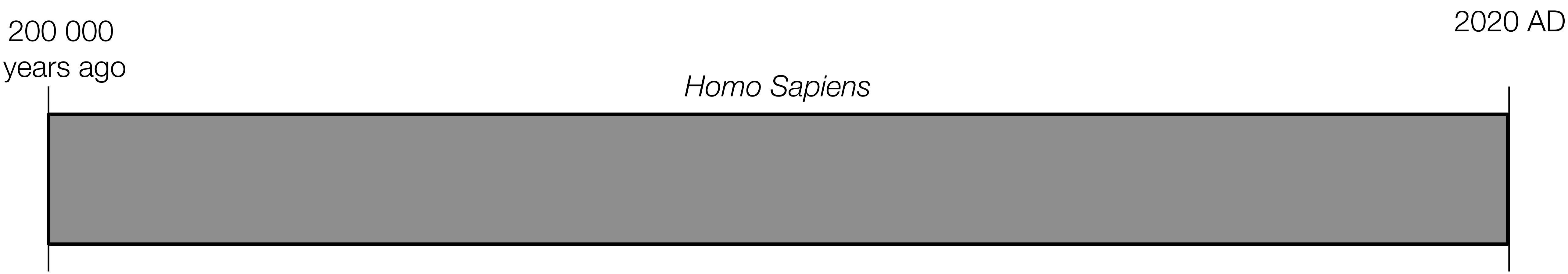
A time-line of humans and cutting tool materials

200 000
years ago

Homo Sapiens

2020 AD

A time-line of humans and cutting tool materials



Obsidian tools from America, which was colonised 38,000-14,000 BC

A time-line of humans and cutting tool materials

Solutrean tools, 20,000–15,000 BC
Sao Saône-et-Loire, France

200 000
years ago

2020 AD

Homo Sapiens

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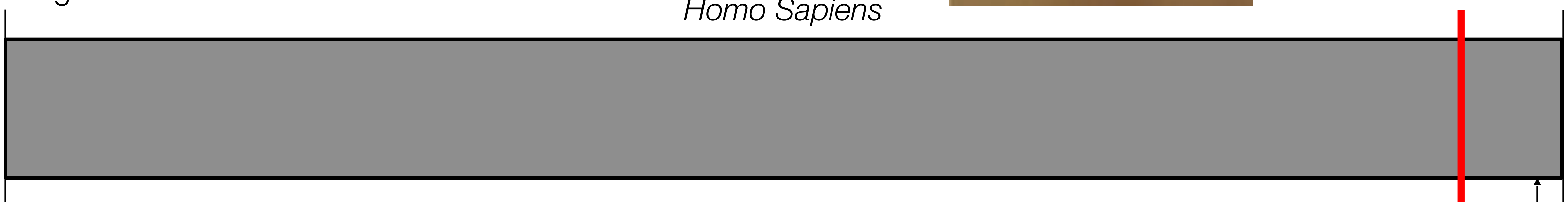
200 000 years ago

Homo Sapiens

9500 BC

2020 AD



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Oldest known man-made metal object

Swedish tools, 2,000–3,000 BC
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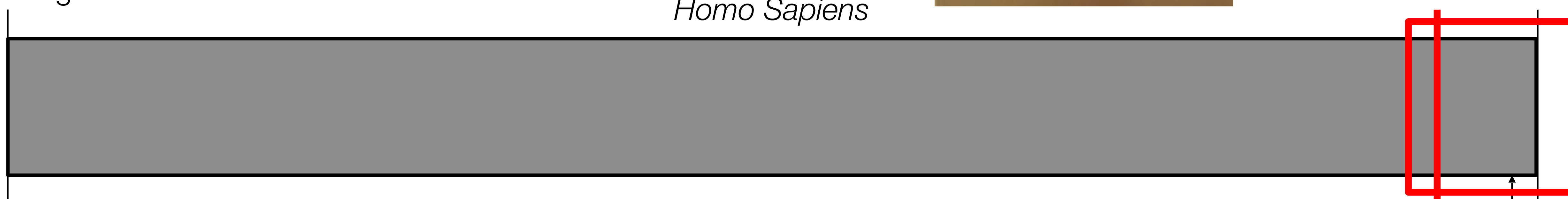

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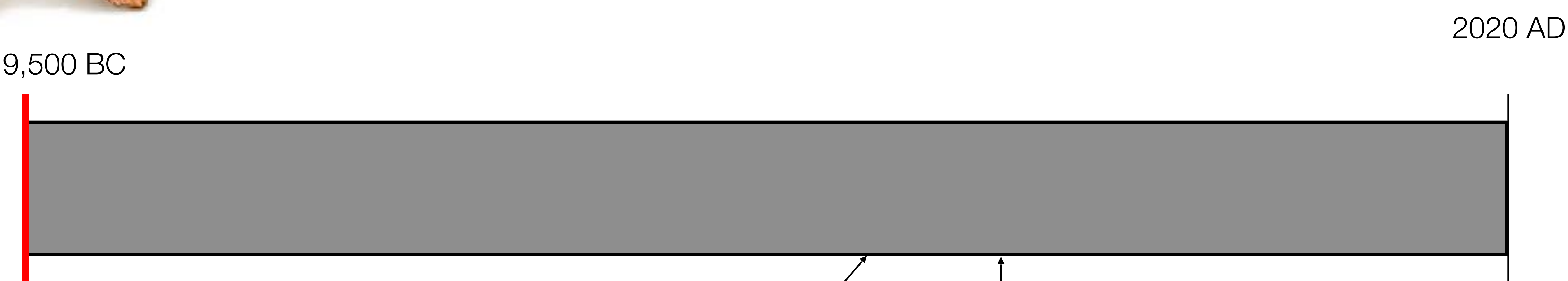


Oldest known man-made metal object:
A small copper object hammered out of a rare natural pure Cu ore.

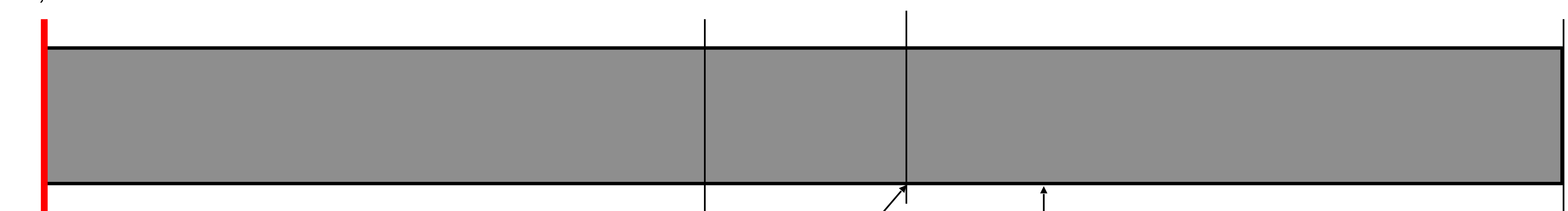
Which other metals exist in pure form in nature?

Swedish stone tools, 2,000–3,000 BC
close to Linköping, Östergötland, Sweden

A time-line of humans and cutting tool materials

Oldest known casted metal object (Cu). Cu melting point is 1085°C, typical camp fire is only about 750°C. What was needed?

Discovery of (Cu,Sn) and (Cu,As) alloying in Mesopotamia: ***Bronze age*** **advent of Metallurgy**



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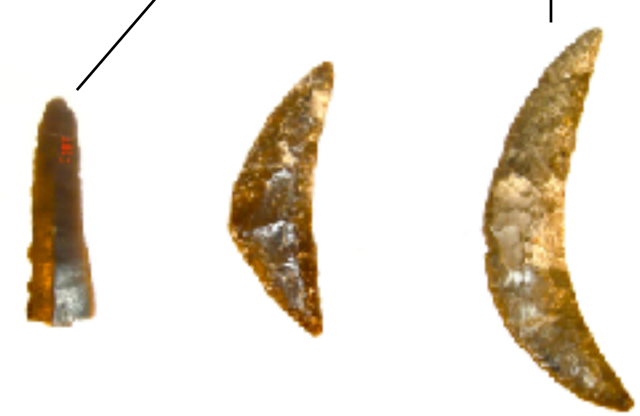

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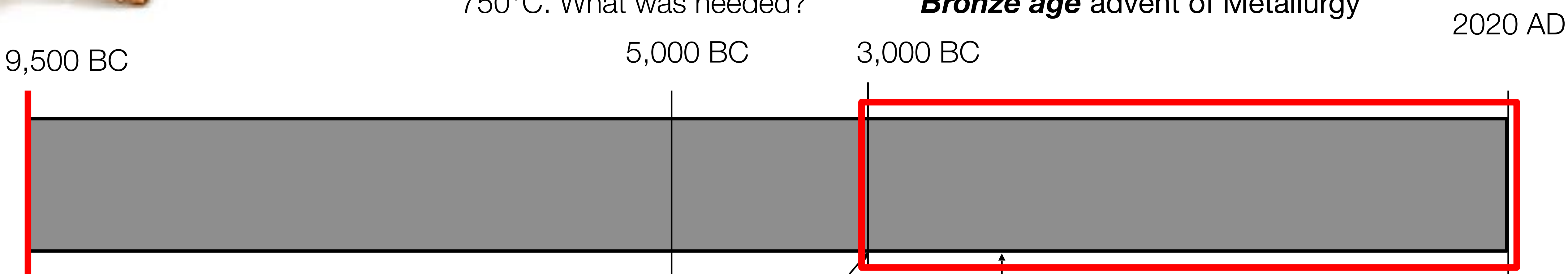

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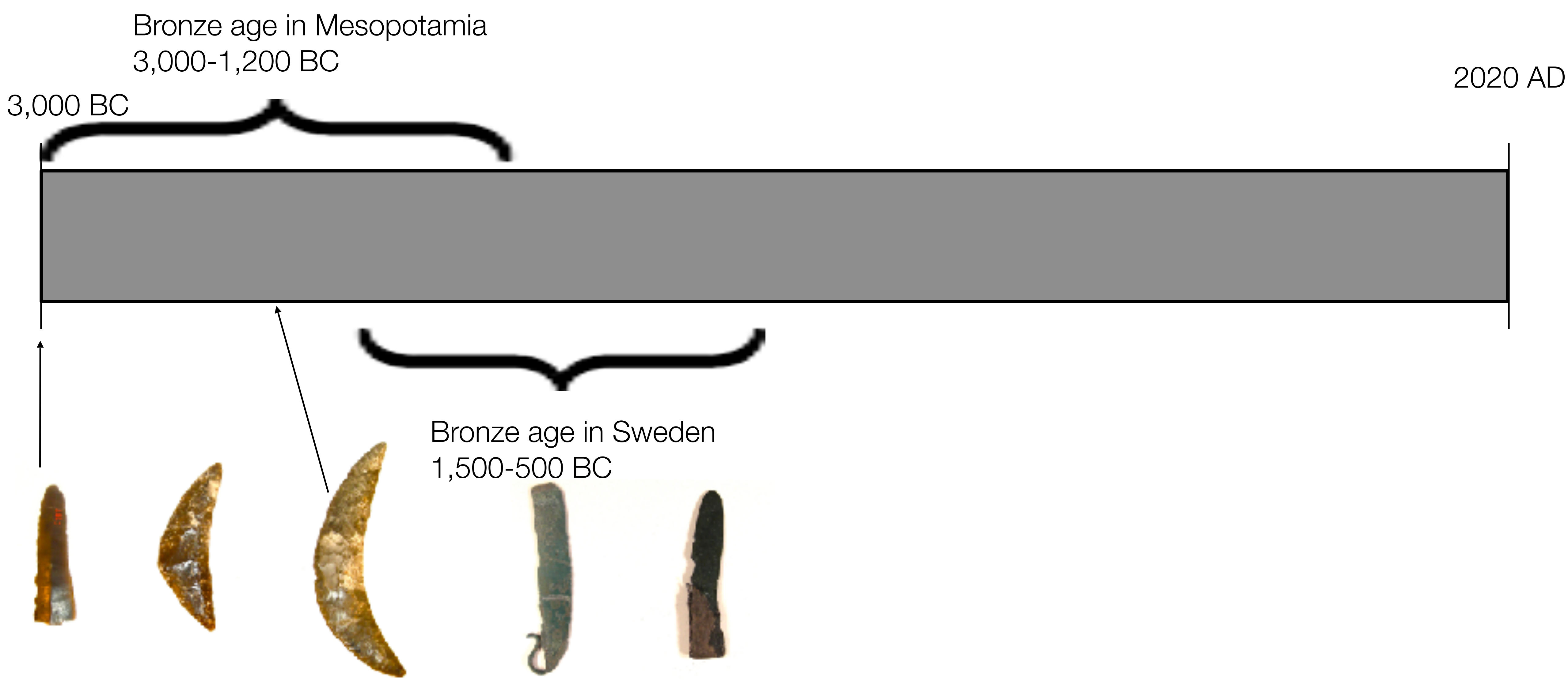


Swedish stone tools, 2,000–3,000 BC
close to Linköping, Östergötland, Sweden

Swedish bronze tools, 800 BC
close to Linköping, Östergötland, Sweden

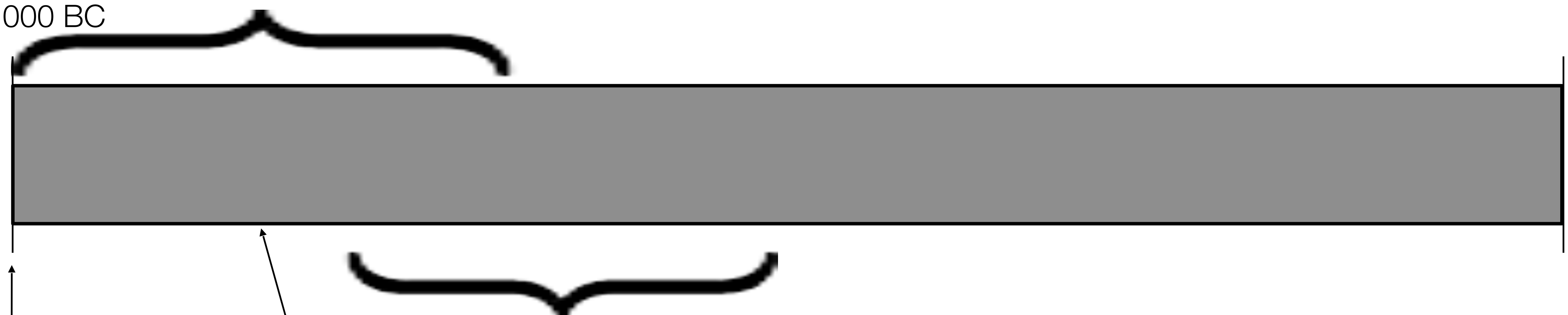
A time-line of humans and cutting tool materials

Oldest known man made iron object: 3,200 BC
Production of Fe objects from meteoric (Fe,Ni)-alloy about 2,500 BC in Mesopotamia: jevelry

Bronze age in Mesopotamia
3,000-1,200 BC

3,000 BC

2020 AD



Bronze age in Sweden
1,500-500 BC

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close to Linköping, Östergötland, Sweden

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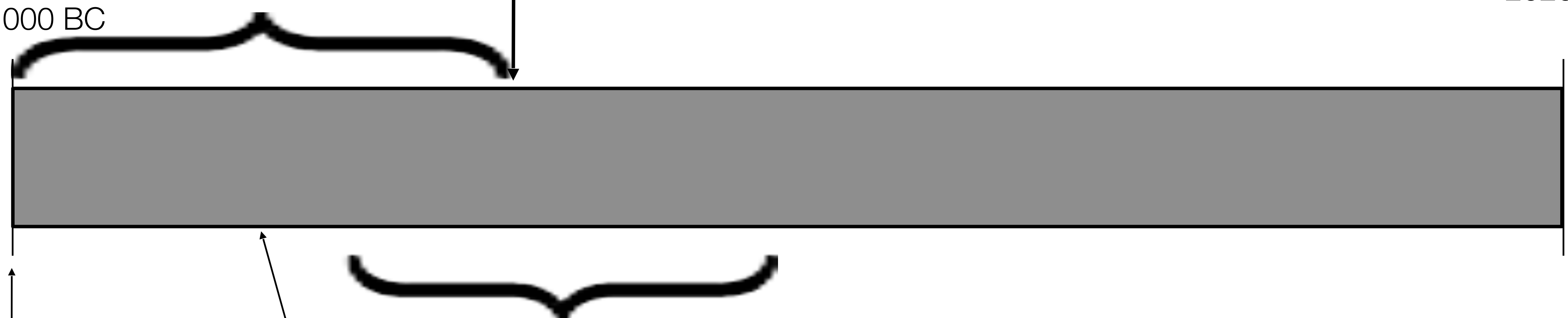
Bronze age in Mesopotamia 3,000-1,200 BC

3,000 BC

2020 AD



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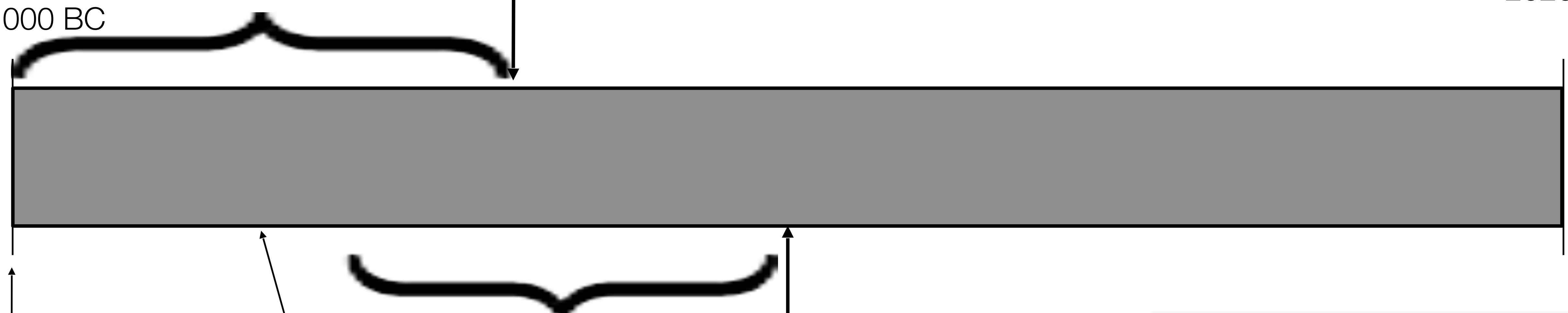

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Iron age start in Sweden 500 BC

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Swedish iron tools, 400-1050 AD Linköping, Östergötland, Sweden

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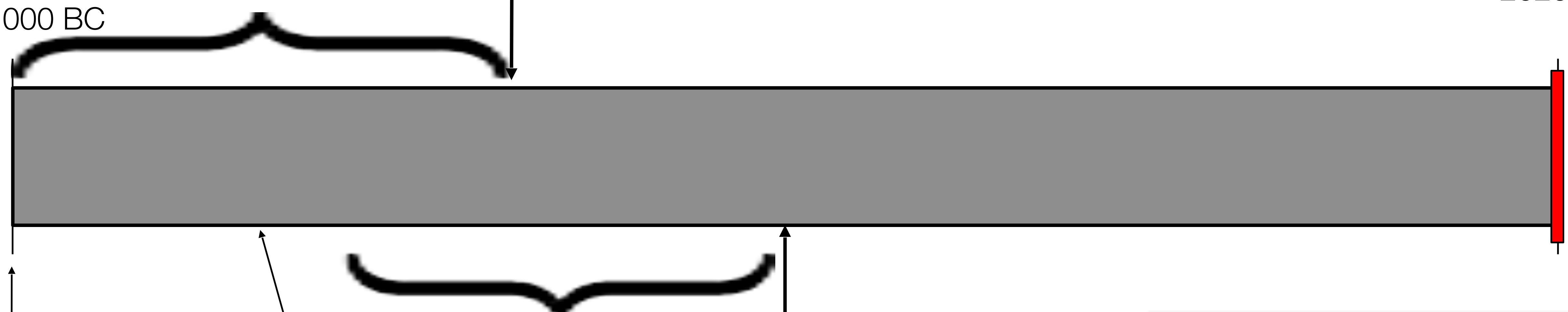
1945-2014:
Silicon based electronics
Hard-metals
Nuclear energy materials
Carbon fibre, composites
Plastic revolution
Nanomaterials

Modern cutting tool

Bronze age in Mesopotamia 3,000-1,200 BC

3,000 BC

2020 AD



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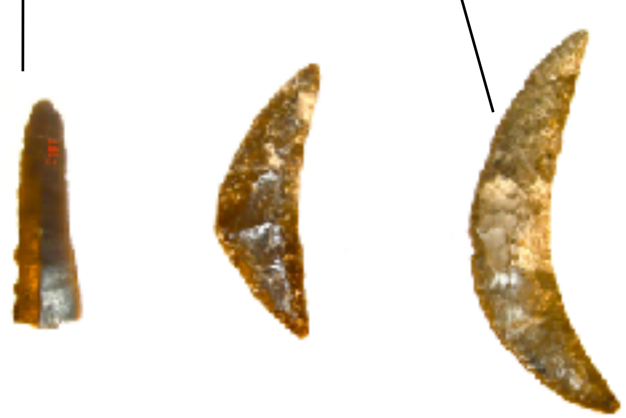

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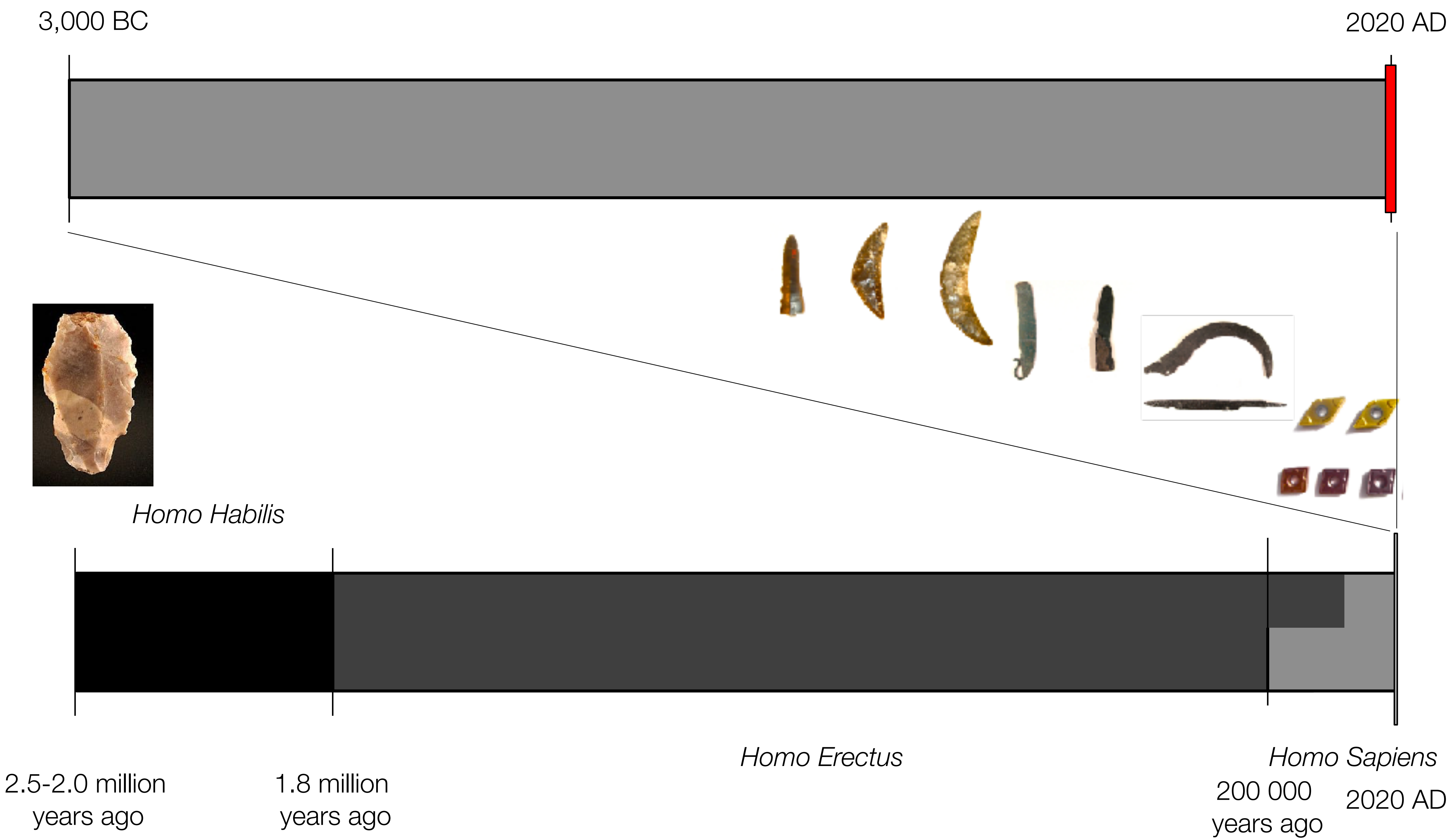


Why is materials development accelerating?

- Pure number: 7,000,000,000 humans on the earth 2012.
  1,000,000,000 1804
  < 15,000 at a possible ”bottle neck” around 70,000 BC

- Economic development: very few people can produce all the food needed, freeing people up to do other things.

- Creation of Societies: Knowledge and innovations can be collected, spread, developed by others without meeting the inventors in person. Writing, school-systems and communication technologies etc.

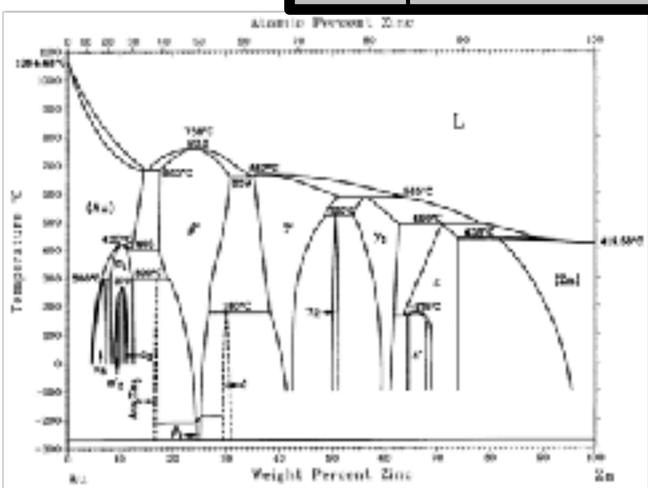
- Nevertheless, up to 100 years ago, materials discoveries were made almost exclusively by an trial-and-error approach. We just made more trials, and learned better from errors.

- The development of ***quantum mechanics, solid state physics, and thermodynamics*** could explain the observed materials structures and properties on an atomic- and nano-scale allowing for ***knowledge-based materials design***: the advent of modern ***Materials Science***

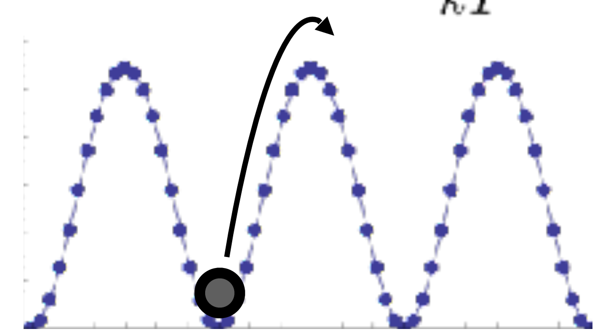
The structure of the course

Phase Stability
Equilibrium Thermodynamics

Diffusion
How atoms move



$$\Gamma = v_0 \exp(\frac{-\Delta E}{kT})$$



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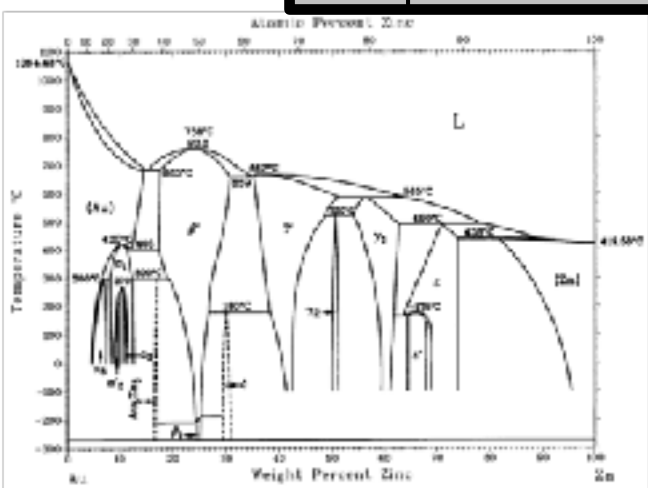

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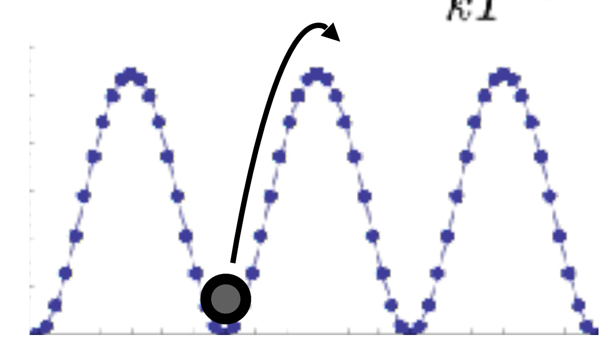
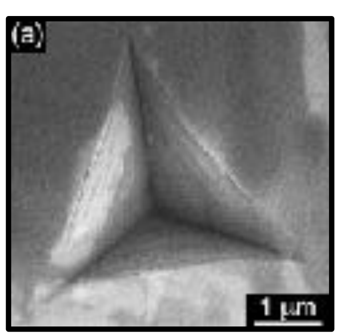
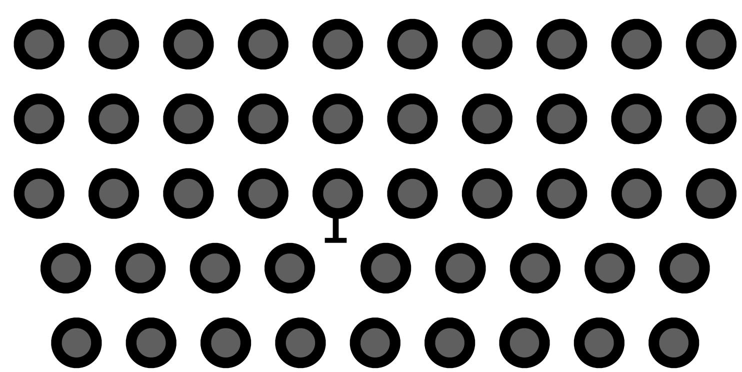


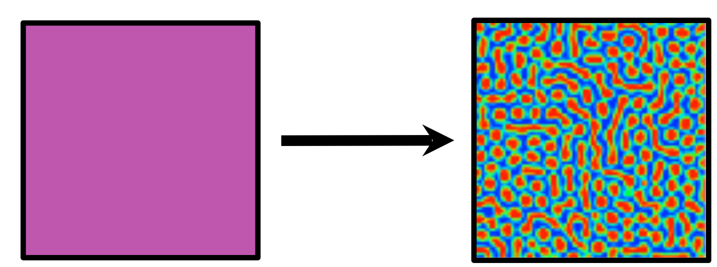
Microstructure



Defects



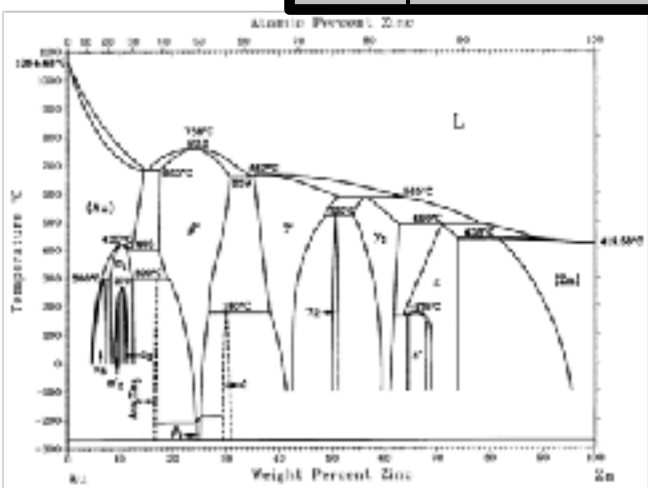
Phase transformations

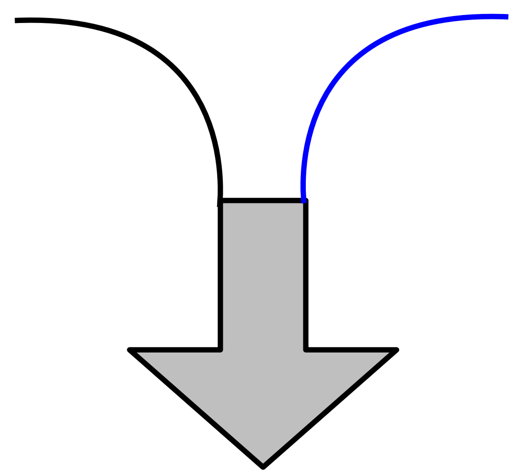


The structure of the course

Phase Stability
Equilibrium Thermodynamics

Diffusion
How atoms move





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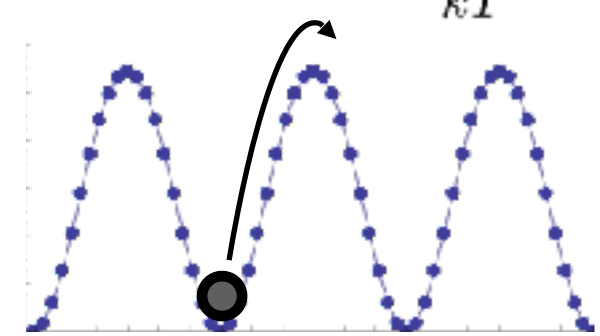

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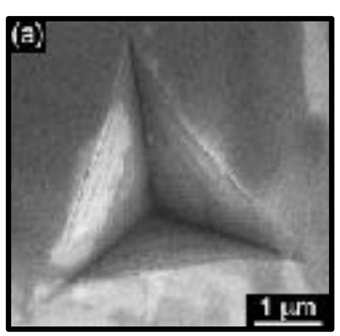

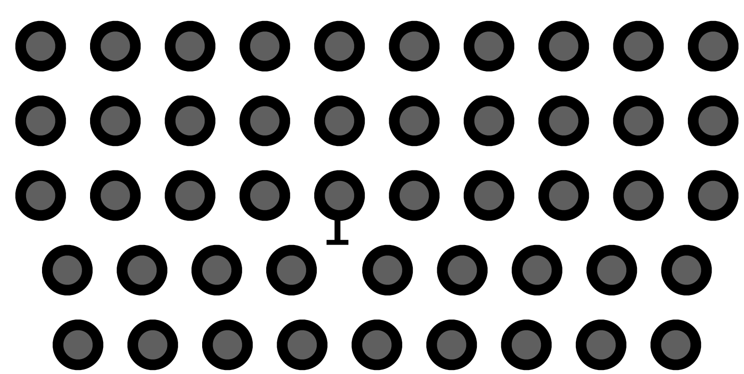

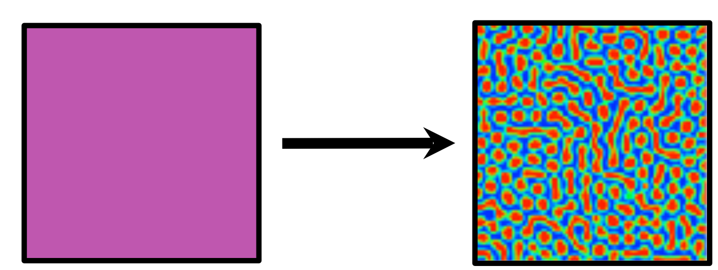

Materials Properties

Course learning objectives

- After passing this course, you are supposed to:
  - Understand the connection between the synthesis, structure, composition, properties and usage of a material.
  - Derive phase stability using a thermodynamic description of liquid and solid phases
  - Describe atomic diffusion in materials with concentration gradients using Fick's and Darken's equations
  - Seek connections with the content of other courses such as solid state physics, thermodynamics, quantum mechanics, crystallography, and metallurgy in order to gain understanding of materials and their properties
  - Utilise the knowledge of functional materials including alloys, nanostructures, and ultra-pure metals in solving complex materials science tasks
  - Analyse mechanical and electrical properties as well as failure mechanisms based on an understanding of atomic-scale defects and the microstructure

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”Föreläsning”
means Lecture or
Problem solving session

18 Scheduled Lectures

6 Scheduled Laborations

Exam: 26 March 14-18

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	Ti 2020-03-10			
	13:15 - 17:00	TFYA21		Laboration
	To 2020-03-12			
	08:15 - 10:00	TFYA21	P36	Föreläsning

”Föreläsning” means Lecture or Problem solving session

18 Scheduled Lectures

6 Scheduled Laborations

Exam: 26 March 14-18

Lecture content

1. Introduction, course information, historical background
2. Thermodynamics of phase stability and phase transformations
3. Theory of Phase diagrams
4. Calculating and constructing Phase Diagrams
5. Diffusion equations, atomic mechanisms
6. Diffusion in alloys
7. Diffusion, concept of moving lattice
8. Microstructure for materials design
9. Point defects, dislocations, stacking faults
10. Solidification - elements
11. Solidification - alloys
12. Diffusional transformations
13. Age hardening
14. Diffusionless transformations
15. Shape memory alloys, amorphous solids, bulk metallic glasses
16. X. Back-up time, questions about the exam, outlook

Laboratory exercises

1. Metallography - optical microscopy
   Davide Gambino
   Metal Microscope Room M218

2. Fractography - electron microscopy
   Babak Bakhit
   SEM-room inside the clean room lab
   Please change to white coat and put on green shoes. Then wait in the air lock for the lab assistant to pick you up.

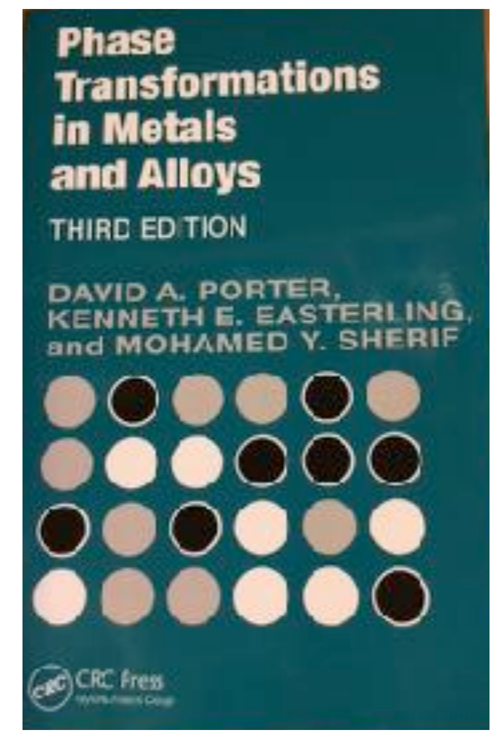
3. Phase transformations - Calorimetry
   M. Amin Gharavi
   Scanning Calorimeter Lab, Room P211

Self-study

- Approximately 116 hours of self studies are recommended
- To support you in this work you have:
  - The course book, including problems and answers.
  - A set of ~80 selected topical problems, the examination will consist of a subset of these problems.
  - Four more complex home assignments that, if correctly solved, gives you bonus-points for the exam
  - Your colleges in the class. Collaborate! (home assignments and the exam should of course be solved individually)
  - Databases of materials properties available on-line and in the library

Course literature

- Main course book: ”Phase Transformations in Metals and Alloys”, David A. Porter, Kenneth E. Easterling, and Mohamed Y. Sherif, CRC Press, Taylor&Francis Group. Third edition.



- This book is practically mandatory for the course.

- Compendia for the three laboratory exercises

- Book and compendia can be bought in the bookstore in Kårallen. If they run out of the book, more can be ordered at ~1 week of delivery time.

Examination to obtain 6 hp

- Written exam, March 26
  - Will consist of 9 problems. These problems will be chosen from the set of topical problems handed out during the course. To pass the exam, points corresponding to 5 solved problems will be needed.

- Home assignments, handed out during the course
  - 4 more complex problems were you should use all available sources of information, and your knowledge from previous courses etc to solve the tasks. If correctly solved, bonus points corresponding to ~2 exam problems will be awarded and accounted for at the exam. Hand-in deadlines Feb 11, Feb 18, Mar 4, and Mar 11 (by email, preferred, but snailmail in my IFM mailbox also ok)

What is a material?

- Every kind of matter which we use to create objects
- Materials can be divided into broad categories
    - Metals: conductive, strong, fracture-resistant
    - Ceramics: hard, brittle, non-conductive
    - Polymers: diverse designable properties, low stability

What are the building blocks of materials?

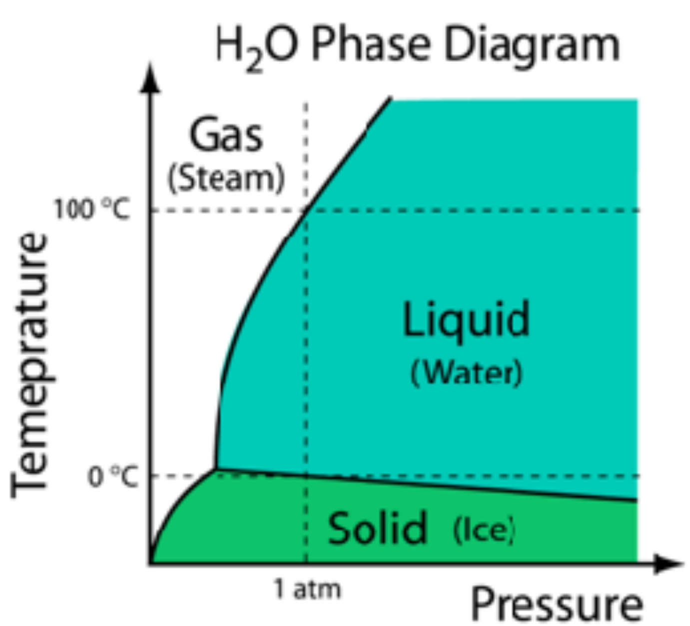
- Atoms
  The fundamental building block in Materials Science, we rarely go deeper. Contributes with electrons and nuclei. Determines the mass and nuclear properties of a material.

- Bonds between atoms
  Bonding in solids is a quantum phenomenon. Electrons lowers their energy by delocalizing over several nuclei.
  The strength of the bonds determines melting points and many other things.

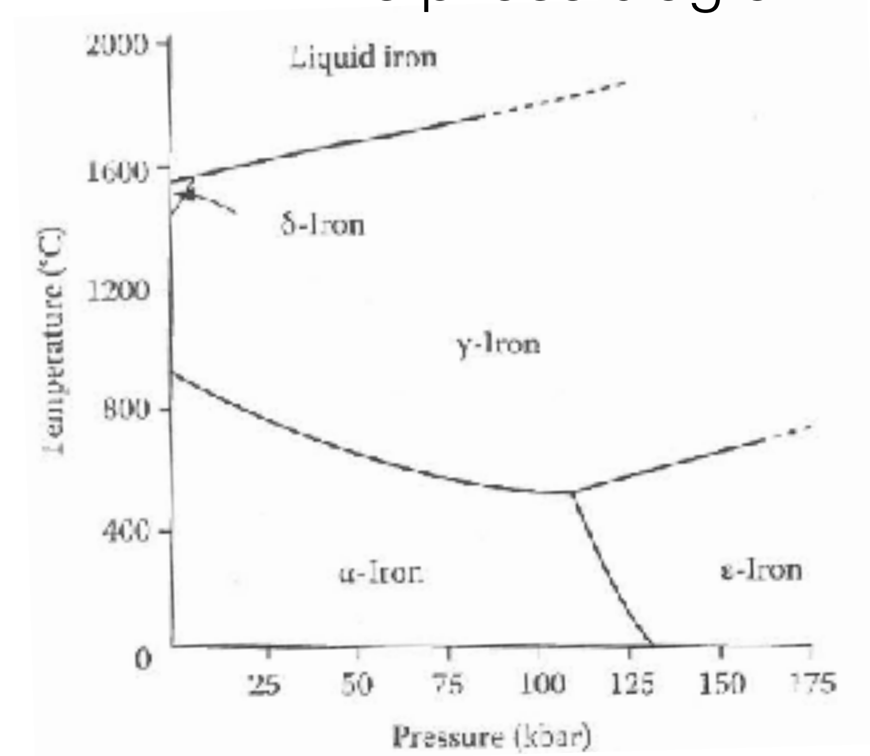
- Phases
  How the atoms are arranged when bonded together, and in what proportions
  - crystal structure and composition

Phases

- In a discussion of the physical properties of materials it is useful to have a word for a specific form of a material: ”Phase”.
- A phase is a chemically and structurally homogenous part of a material.
- A phase has the same physical properties throughout.
- A Phase Diagram shows which phases that constitute equilibrium under different conditions: composition, temperature, pressure.



Fe phase diagram



Binary Phase Diagrams

- Binary metal alloys is a major topic in this course.
- Binary phase diagrams tell you which phases that can be expected for each composition and temperature.
- Pressure is most often not included, kept fixed at 1 atm (a negligibly low pressure when most metals are concerned)