5.5 Mixes

5.5.1 What's in a Name?

What are You?

"The complications start now", I just threatened (or promised) at the end of the preceding chapter. That's because so far I only dealt with simple and rather perfect crystals that contained some comparatively simple defects. What we will do now is to consider mixes of all kinds of materials.
The first complication that comes up are the names for complicated materials. Let's ponder a few easy questions to see what I mean:

- What do you call the following things (the first four are crystals):

  - *Aluminum oxide* or **corund** (Al_2O_3) containing a few substitutional chromium (Cr) or titanium (Ti) atoms?
  - *Copper* (Cu) mixed up with 10 % tin (Sn)?
  - *Silicon* with a tiny bit of substitutional phosphorous (P) or boron (B)?
  - *Iron* containing about 1 % of carbon (C) ?
  - A *human* with a Y chromosome instead of an X chromosome?

- You do *not* call it what it actually is: the ideal thing plus a defect. You call it:

  - It's *ruby* or *sapphire*, respectively, instead of corund with a substitutional amount of extrinsic point defects.
  - It's *Bronze*, instead of: dirty copper.
  - It's n-type or p-type silicon, resp., and these two basic silicon versions are at least as different as males and females. More generally we call it *doped* or extrinsic silicon but never (intrinsic) silicon with some point defects.
  - It's *Steel* instead of iron with some carbon.
  - It's a *male* instead of: defective female.

In other words: where *exactly* is the change-over from copper (Cu) with some impurity tin (Sn) atoms to the copper - tin *alloy* that is called *bronze*? From slightly dirty wrought iron to steel?
In yet other words: When do we change from one reference system (iron, copper) to another one (bronze, steel)?

- The answer is simple: there is no clear answer. These letters are **black**. These here are **grey**, and .
  Are the ones here grey or still black? They are actually a tiny bit grey. You could call them ideal black *contaminated* with a tiny bit of white. In the next sentence the degree of "white contamination" changes slowly from 0 % to 100 %.

  I n this s entence the whit e increa ses slow l . OK - once more with a different back ground color:

  I n this s entence the whit e increa ses slow ly

  At which letter is the turnover from contaminated black (or white) to grey? There is simply no way of telling! It is a matter of "taste" or convenience.

I'm talking about names for certain materials and mixtures of materials. In essence, there are many words for special materials, and there is no harm done in using them whenever the meaning is sufficiently clear. Before I introduce some of the more important names and classifications of materials, I want to point out that the problem of defining a kind of clear boundary for a mix of things, with pure "A" being on one side, and pure "B" on the other, is very common and the source of many misunderstandings not only in science but also in society. Here are some examples:

- One vacancy (= white) is a point defect and so is a double vacancy—two vacancies next to each other. A tri-vacancy will still be a point defect but a 45.631-vacancy we call a **void** (= black), and this is a three-dimensional defect. Where is the switch-over?
- Copper (Cu) is definitely a *metal* , so is lead (Pb). How about their neighbors in the periodic table? To the right of copper we find zinc (Zn), gallium (Ga), germanium (Ge), and germanium is most definitely a *semiconductor*. What about gallium?
  Above lead to we find tin (Sn), germanium (Ge), silicon (Si). Once more we move form a metal to a semiconductor. Is tin a metal? It is often called a "semi-metal". This is just to show that even a name like *"metal"*, absolutely unambiguous as you might have thought, has a "grey" side. Nevertheless, we sure know a real metal (= white) or non-metal (= black) when we see one. How about the grey ones?
- "Soziale Gerechtigkeit" (social fairness or justness) is a big word in German politics. It boils down to money being transferred from the more prosperous to the more disadvantaged people. When will politicians consider that social fairness (= white) has been established, considering that right now it is not? The relevant department of the Federal Government presently transfers about 40 % of the total (tax) income from rich to poor. By (almost) general consent, this is not enough. How can you find the right number?

- In today's (May 2012) newspaper I read in an interview with the art director of a huge art show in Kassel, Germany: "There is no fundamental difference between women and dogs. Neither between dogs and the atoms of my bracelet. A tomato is the cultural product of the tomato plant (*and thus art*)".
  Well. Just because some women, if compared to some (female) dogs....
  I think I made my point.
- A knife has a short blade and and sword a long one. Then there are long knifes and short swords. At what length, exactly, changes a long knife blade into a short sword blade?

Now let's look at some notations concerning materials in this context. This is essentially an exercise about the names that signify the "nature" of the objects we encounter in daily life. It is unavoidable that we always encounter the "black - white" problem from above, and that means that you have to take these words with a grain of salt.

- The first list of names concerns, in a general way, the *structure* and composition of materials.

Names Related to Structure and Composition

Metals, Non-Metals, Natural Materials

- This is the classical threesome, used in all old materials science text books, with examples like:

Metals	Non-Metals	Natural Materials
Iron (Fe) Copper (Cu) Gold (Au) Bronze brass Steel ..	Glass (dirty Si_2O) Quartz (SiO_2) Ceramics like Al_2O_3, ZrO_2, UO_2 Polymers Graphite	Wood Coal (very dirty carbon) Rubber Sand, gravel, Rocks, Marble Gemstones

- Designations like "metals" or "rocks" do have some value, of course, for communication with other people. Everybody has some idea what you are talking about. I will keep using words like "metal" and so on as long as it is reasonably clear what is meant.
  Otherwise forget that classification system. The world is no longer as simple as it used to be.

Alloys

- The name is typically (but not exclusively) applied to mixes of metals with a whole range of concentrations. Mostly one element dominates, and we talk then for example about copper alloys.
  If we only consider alloys of copper and *one* other element, we have, in principle about 90 possibilities to make copper alloys, since we have 92 elements. In practice, a number of elements will not alloy with copper (e.g. the noble gases) but there is still a large number of possibilities if we only consider all the other metals as alloying partners. For any combination **Cu** - metal **X**, we can look at a whole range of concentrations for **X**.
  Then we can alloy not just one, but several other elements with copper (always making sure that copper accounts for more than 50 % of the mix, so we are justified to call it a copper alloy).
  In other words: While we have "only" 92 elements (about 70 of which are metals), we can produce close to infinitely many combinations. These include *chemical compounds* like Copper chlorides (CuCl, $CuCl_2$, $Cu_3Cl_2(OH)_4$,...) for exactly defined concentrations of **X** that are neither alloys nor metals, but also an infinity of *alloys* that are metals - more or less (see above).
  Chemistry, as a discipline worries more about well-defined chemical compounds; alloys are more in the domain of Materials Science.
  How could you tell if given substance is an alloy (= white) or a chemical compound (= black)? A simple carbon steel would be counted among the alloys, but if you look at it closely (at room temperature) you find that it actually a mix of the chemical compounds iron (Fe) and cementite (Fe_3C).
  To some extent we avoid the problem by giving some special mixes names. "Bronze" for some copper alloys, "brass" for some others. "Steel" is the name for all kinds of iron alloys as long as iron is being dominant. It might be differentiated by qualifiers like "high-alloy steel, low carbon steel, ultrahigh carbon steel, ... , but those are just names giving an idea of what we talk about and not precise definitions. Where, exactly would you put the switch-over between low-carbon steel ("white") and medium carbon steel ("black")?

Chemical Compound

- Well - I already gave you that right above. In a proper (= white) *chemical compound* the ratios of the atoms involved have precise (integer) numbers. There is some "grey" here too, but I won't go into that.
  I might add that chemical compounds can have properties that are radically different from that of their constituents. Hydrogen (H) and oxygen (O) are gases, liquid H_2O is known as *water*, solid H_2O we call ice. Chlorine (Cl) is a deadly gas, sodium (Na) is a (dangerous!) metal. NaCl, known as (rock) salt, is a relatively harmless and useful insulator.

In contrast, copper *alloys* like bronze (typically with tin (Sn) as partner) or brass (zinc as partner) are also quite different from pure copper, but not radically so.

Composite Materials

Composite materials consist of a mix of at least two other (solid) materials on a scale much larger than the atomic scale. Usually the term is used in connection with materials where the constituents where deliberately mixed by humans and not by nature. Sometimes the term **Compound material** is used for composites but that is not a good name and should be avoided.
Examples are:

- Concrete, consisting of stones embedded in cement. Cement is already a composite material in its own right; stones might be. already a composite material. Add some steel to concrete and you now have a composite material with at least three different constituents.
  And yes, the constituents of a composite material could be alloys, chemical compounds or other composites. "Stones", for example, are quite often composites of different minerals.
- Carbon or glass fibers in epoxy, i.e. the stuff used for modern air planes, Formula 1 cars, boat hulls and so on.
- Composite bows, containing at least two different kinds of wood (plus things like sinew, horn, ...)
- Wood; actually a *natural* composite material consisting of cellulose and lignin.
- **Composite swords** made at least from two different kinds of steel. I won't call them composite swords, however, since this produces wrong associations.

Single Phase and Multi Phase Materials

A phase is an expression of some material that is well-defined and uniform on an atomic scale. A chemical compound like water or rock salt is always a single phase but more complex stuff could also be a single phase. We are going to spend a lot of time on that so I won't say more at this point.
A multi-phase material is a composite of several phases. In contrast to what we generally call composites, the ingredients cannot be other composites and they usually "make themselves", for example when steel cools down.

Names for Properties and Functions

We have a different set of names for materials that concern not so much their structure but primarily their properties and functions.

Examples are

- **Superconductors**, **Conductors** , **Semiconductors**, **Insulators, Dielectrics**. These names refer to direct electrical properties.
- **Ferromagnets**, **Ferrimagents**, **Paramagnets**, **Diamagnets**. You guessed it.
- **Thermoplasts**, **duroplasts**, **elastomers** for basic kinds of polymers.

In the world of steels there are many qualifiers relative to some function or property: **Stainless steel**, **austenitic steel**, **machining steel**, **tool steel**,

Names for Processing

Doping

Doping *typically* means that you introduce small amounts of well-defined foreign atoms into a semiconductor; mostly as substitutional impurity atoms. However, in other branches of Materials Science, the word "doping" might also be used for relatively large amounts of some stuff introduced into some material, for example when "organic semiconductors" are concerned.
Quite frequently the word is simply used to refer to an electronic property. "My gallium nitride (GaN) is n-doped", for example, only refers to an effect of doping and leaves open how it was done.
Doping typically changes the properties of the material more or less in a way you like.
Never confuse doping with:

Contamination

Pretty much the same as doping - getting some other atoms in there - except that you don't like it. The properties may change a lot, just as with doping, but not in the way you want it.

Ceramics

You might wonder why I list "ceramics" under processing. The reason is that the word typically refers to materials that have been made by sintering, a powder processing technique. It is, however, an ambiguous designation. Some people call everything that's brittle a ceramic, for example.

Then we have words like alloying, tempering, annealing, normalizing, quenching, ... Sometimes the meaning is rather general, sometime it is specific.
I won't go into this any more except to point our that some names for steel hint at the processing involved, for example "maraging steel" (short for "martensitic aging" steel) or "austempered steel" (short for "tempering in the austenite region").