Chapter 3

Design and Designing

In Italian there is one inclusive word for design and engineering - la *progettazione*; a designer or an engineer is “il *progettista*.” Translated literally, “*il progetto*” is the plan. In English, too, the word “design” is defined as “the plan,” with an even wider spectrum of meanings: design with regard to fashion - like hats; or with regard to aerodynamics and fluids - like that of turbine blades; or even with regard to states of mind. Such breadth of meaning creates opportunities for confusion. To avoid this, we will speak of *technical design, industrial design and product design*, using these words with the following sense.

Technical (or engineering) design includes the aspects of design that bear on the proper technical functioning of the product: its mechanical and thermal performance, cost, and durability. We shall call these, collectively, the technical attributes of the product – attributes that describe how it works and how it is made. **Industrial design** includes the aspects of design that bear on the satisfaction afforded by the product: the visual and tactile attributes, associations and perceptions, historical antecedents - attributes that describe its personality or character. **Product design**, in the sense we use it here, means the synthesis of technical and industrial design to create successful products.

There is a risk in drawing these distinctions that technical and industrial design will be seen as separate, unconnected activities. A more balanced view is that they form a continuum, that they are simply parts of the overall design process. But while technical design utilizes well-established methods and sophisticated computer-based tools, industrial design cannot so easily be made systematic or quantitative. Unlike the technical attributes, which are absolute and precisely specified, many attributes of industrial design depend on culture and on time: the Japanese ideal of beauty differs from that of the European; and what is beautiful to one generation can appear ugly to the next. *Scientific and technical language and thinking work well when ideas can be expressed explicitly and precisely, but these break down when the ideas are imprecise, or involve subjective appreciation or taste; then, other ways of thinking are needed*.

Ways of Thinking

Technical design relies on deductive reasoning – thinking based on logic and analysis. Deductive reasoning, applied to the selection of materials, is described more fully in Chapter 7. It lends itself to formulation as a set of steps, often involving mathematical analysis. Industrial design, by contrast, relies on inductive reasoning – synthesis, drawing on previous experience. Inductive methods for selecting materials, also explored in Chapter 7, use perception and visualization. These we need to explore more fully since they are central to the discussion that follows.

Observation and Perception

Imagine yourself to be standing in a motorcycle tradeshow behind two men who are looking at a Harley Davidson. The Harley has technical attributes, listed in its specification: weight, number of cylinders, power, maximum speed, the material of which the frame is made – these and many other attributes can be precisely defined and accurately measured. The Harley also has aesthetic attributes – it is black, metallic and loud. The two men see the same motorcycle but they perceive it in different ways. In the mind of one is an ideal image of a smooth, yellow, urban scooter, without visible mechanical parts, clean lines and trendy styling; he perceives the Harley as heavy, extravagant and dangerous. The ideal in the mind of the other is an image of an open road, a black leather bodysuit, a helmet with darkened visor, twin-exhausts; he perceives the Harley as powerful, authoritative, an expression of freedom.

Perception is the result of interpreting what is observed. Two observers of the same product will perceive it in different ways, ways that derive from their reaction to the physical object they see and the accumulated mental images and experiences they carry with them. Both observation and perception contribute to creativity in design, and here it is necessary that we sharpen the definition of four terms we will use to describe, in increasing order of abstraction, the attributes of products - particularly those relating to industrial design and the personality of a product.

3.1 Virtual Violin?
The form of the violin is an essential part of its personality. In this electronic violin, the ghost-like form both makes the connection to the original and suggests the transmutation that has taken place. (Courtesy Yamaha Corp.)

· *Aesthetic attributes* are those that relate directly to the senses: sight, touch, taste, smell, hearing; those of sight include the form, color and texture of a material or product.

· *Attributes of association* are those that make a connection to a time, place, event or person – thus a jeep has military associations, gold has associations of wealth, the color black, in some cultures but not all, of death.

· *Perceived attributes* describe a reaction to a material or product – that it is sophisticated, or modern, or humorous, for instance.

· *Emotional attributes* describe how a material or product makes you feel – happy, sad, threatened perhaps – “emotional ergonomics,” in the words of Richard Seymour of SeymourPowell, London.

To these we add the word *style.* Styles have names: Art Nouveau, Art Deco, Modernist, Post-Modern, etc. Each is shorthand, so to speak, for a particular grouping of aesthetic, perceived and emotional attributes and associations – one about which there is general agreement. Styles, sometimes, are linked to certain materials, but it cannot be said that a material has a style, only that it acquires one when it becomes part of a product. Examples developed later in this and the next chapter will make these distinctions clearer.

3.2 Left Brain, Right Brain
Thinking from the left or right – the first seeking solutions by logic and analysis, the second seeking solutions by synthesizing elements from recalled or imagined images or analogies.

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Verbal-Mathematical and Visual Thinking

Writers such as McKim,‹ discussing ways in which the human brain manipulates information in order to reason, distinguish two rather different processes (3.2). The first, the domain of the left-hemisphere of the brain, utilizes verbal reasoning and mathematical procedures. It moves from the known to the unknown by analysis – an essentially linear, sequential path. The second, the domain of the right-hemisphere, utilizes images – both remembered and imagined. It creates the unknown from the known by synthesis – by dissecting, recombining, permuting, and morphing ideas and images. The first way of thinking, the verbal-mathematical, is based on learned rules of grammar and logic. The second way of thinking, the visual, makes greater use of the imagination; it is less structured but allows greater conceptual jumps through free association.

Think for a moment about the following example of the way you store visual information. You probably know and recognize several hundred people, perhaps many more. Could you, if asked to draw a recognizable picture of any one of them, do so? Most people can’t; many can’t even conjure up a picture of the face in their “mind’s eye” (their imagination). This suggests that the visual image is stored only in a very crude way. Yet if you unexpectedly encountered a person that you know in – say – Los Angeles International Airport, you would instantly distinguish them from the thousands of other people there. Recognition of a face or a place requires a detailed comparison of a visual image with an image stored in the mind, seeking a match of a very subtle kind – and the average person can store enough information to recognize and distinguish not one, but hundreds of these. The way the mind stores images is not well understood but it is clear that its image database is very large and, when triggered, capable of very rapid access and great precision.

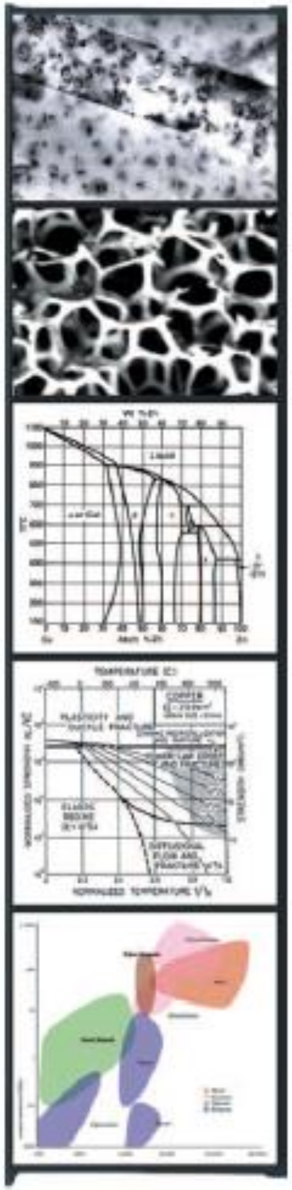
Creativity in design (both technical and industrial) involves the free association and combination of images to achieve a desired set of attributes. The images may be visual – observed objects, photographs, sketches and drawings – or mental – stored in the memory and imagination of the designer.

Visual Thinking in Material Science

The word “science” immediately suggests deductive reasoning – analysis. But creative scientists from Leonardo da Vinci and Newton to Einstein and Crick/Watson testify that their moments of great insights arose as much from synthesis – visual thinking – as analysis. **Material science, particularly, makes use of images for communication and as a way of thinking** (3.3). Venn diagrams and flowcharts illustrate relationships and procedures; bar charts and graphs show magnitudes and numerical trends. Schematics display molecular structures, show how mechanisms work or how equipment functions. Information can be more densely packed in diagrams and images that show relationships. Phase diagrams relate the regimes of stability of competing alloys. Micrographs reveal structural similarities between differing materials, suggesting, perhaps, that a heat-treatment used for one might be effective for another. Deformation mechanism maps relate the regimes

of dominance of competing deformation mechanisms. Material property charts› relate a population of materials in material property space, a space with many dimensions. Each of these captures a vast amount of information and compresses it into a single image, revealing patterns in the data that words and equations do not. It is here that they become a tool not only for communication, but also for reasoning.

The power of the visual image lies in the ease with which it can be manipulated by the mind and its ability to trigger creative thought. A picture of a car tail-light made of acrylic, taken to show its transparency and ability to be colored, reveals much more: that it can be molded to a complex shape, that it can withstand water and oil, and that it is robust enough to cope unprotected with use in the street. Diagrams showing relationships, particularly, have the power to trigger new ideas – examples in Chapter 4 will show how plotting material information can suggest novel material composites and combinations. Without the visual image, these ideas do not so easily suggest themselves. Visual communication and reasoning, then, have a long-established place in the world of material science. But how are they used in design? To answer that we must examine the design process itself.



3.3 Images from Material Science

Some of the ways visual images occur in material science (top to bottom): Electron micrographs; Optical micrographs; Phase diagrams; Deformation mechanism maps; Material property charts.

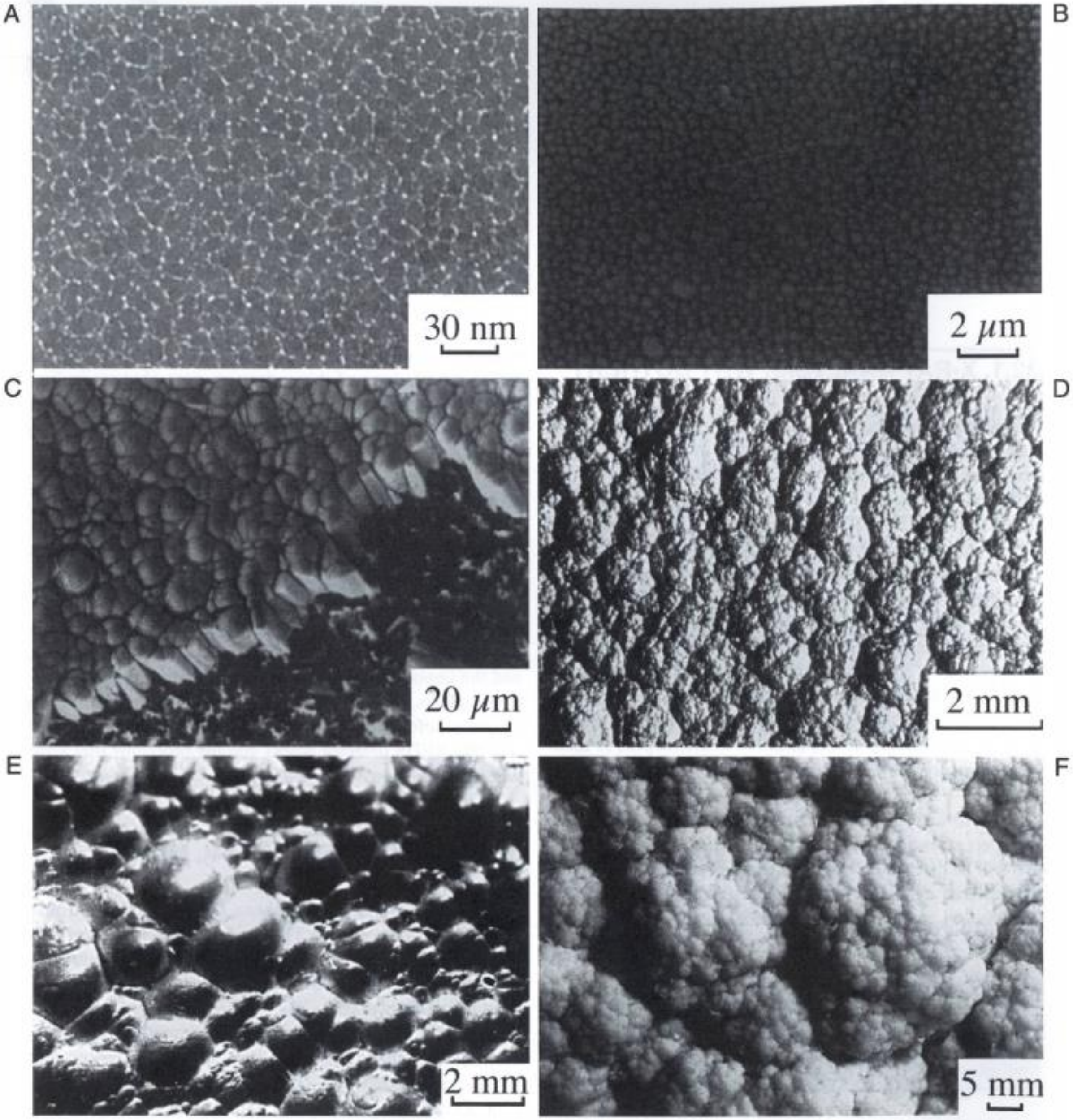


Figure 32.1. Six images of various microstructures, spanning the dimensional range from nanometers to millimeters. The images were taken with TEMs, SEMs, and light microscopes, but the characteristic structures are very similar, and it is not possible, without prior knowledge, to identify the samples.

Images

EDX Spectra

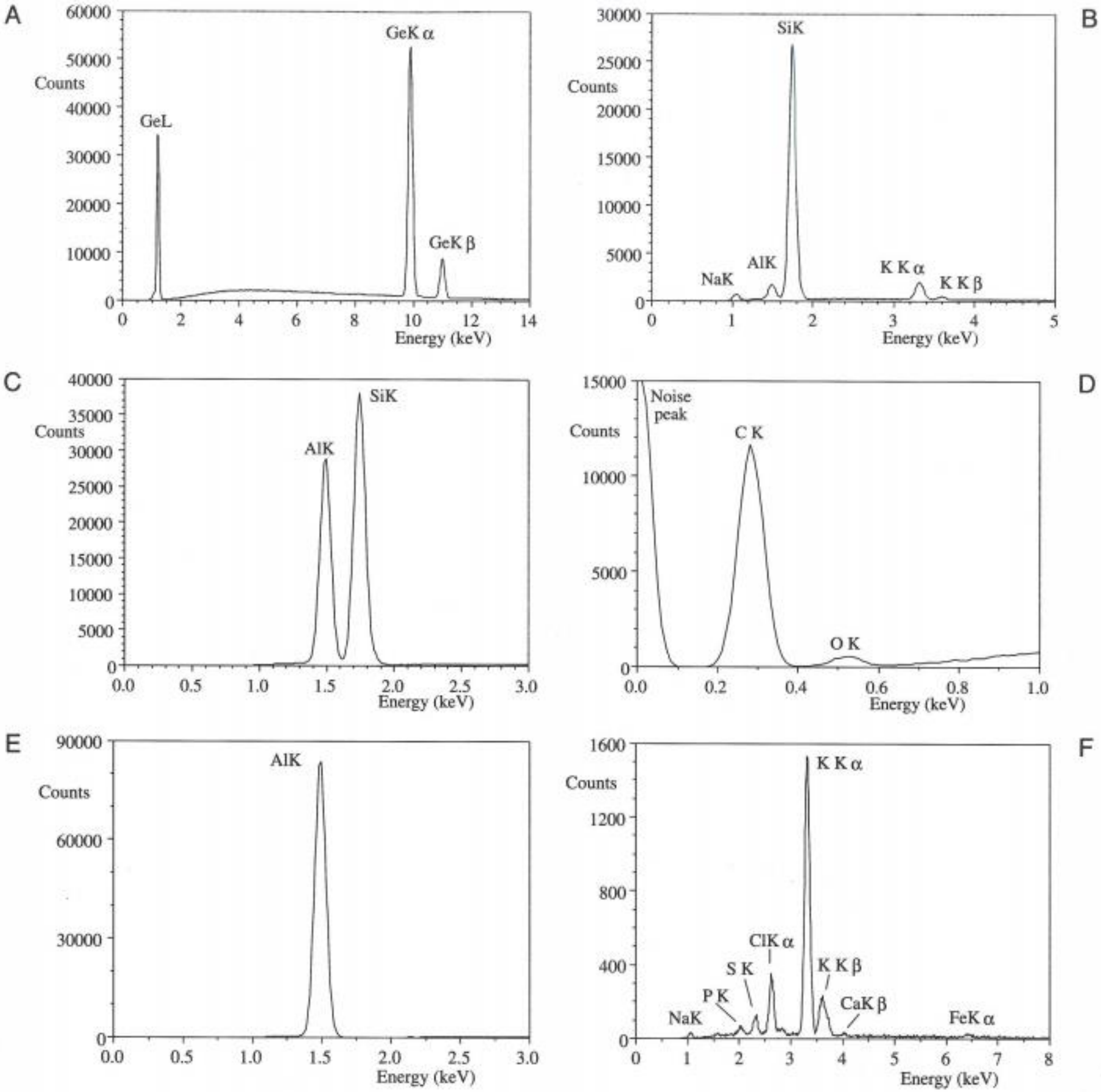


Figure 32.2. XEDS spectra from the six materials in Figure 32.1. Each spectrum is clearly different from the others, and helps to identify the samples as (A) pure Ge, (B) silica glass, (C) Al evaporated on a Si substrate, (D) pyrolitic graphite, (E) pure Al, and (F) a cauliflower.

Phase diagram

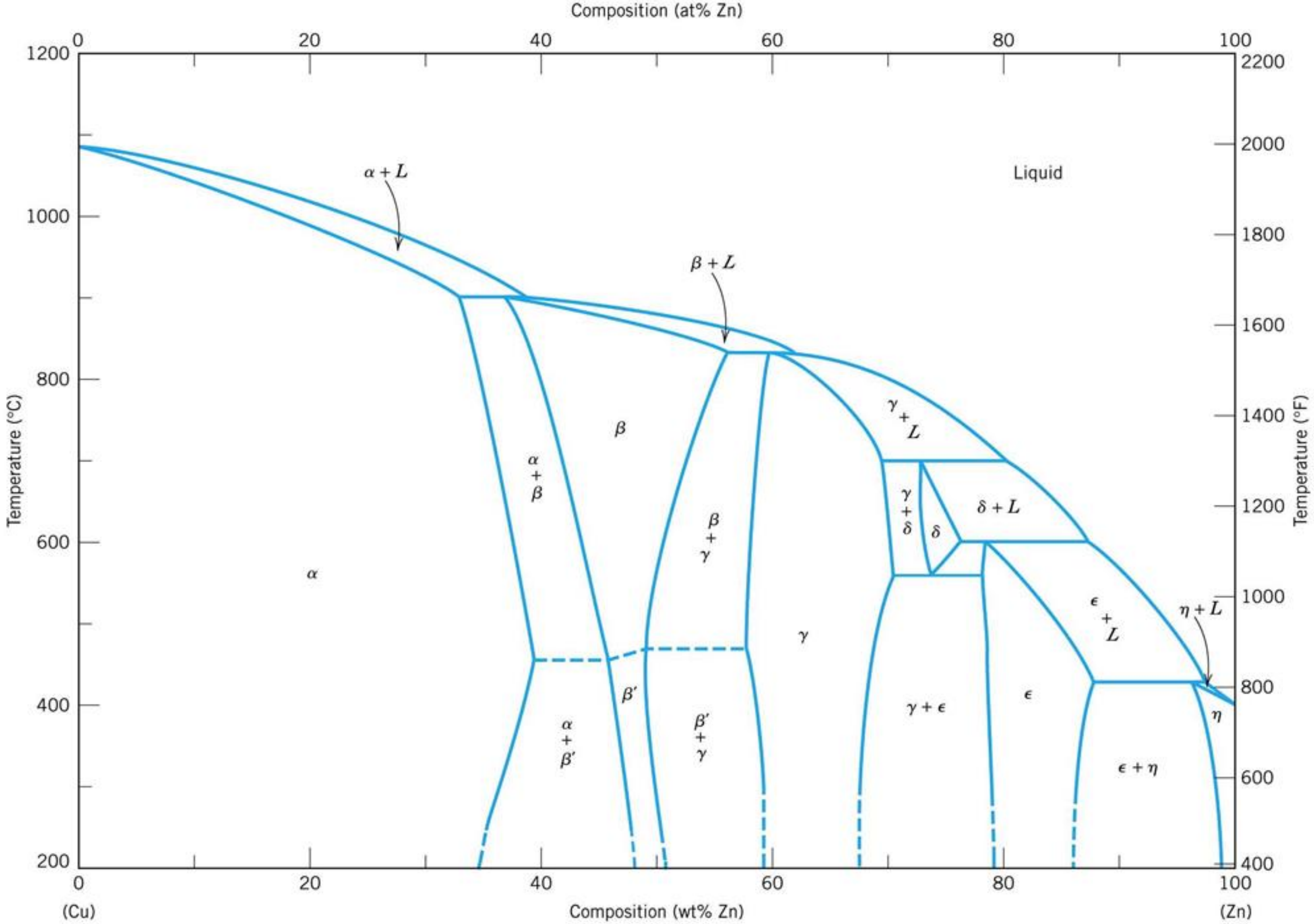
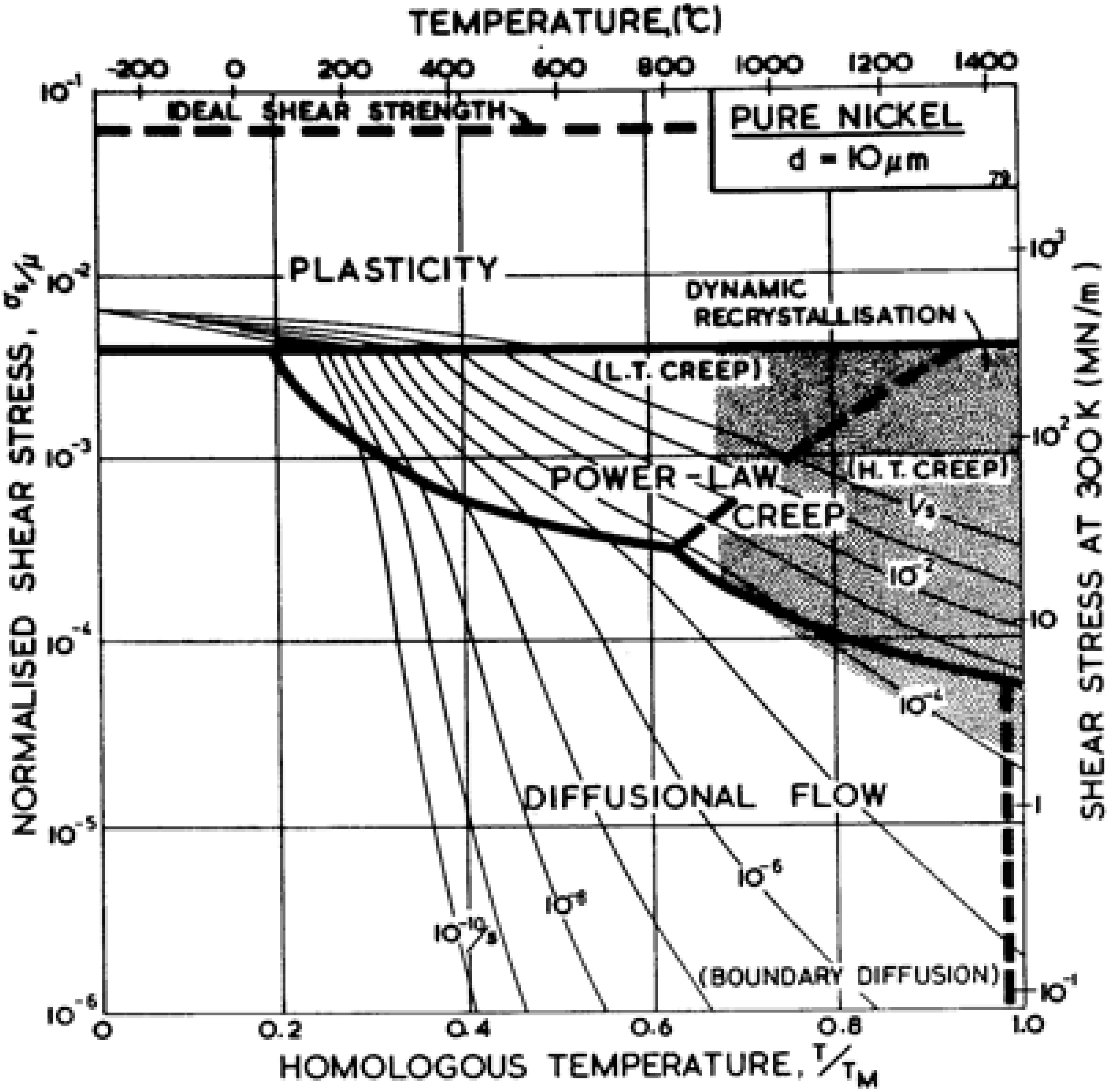
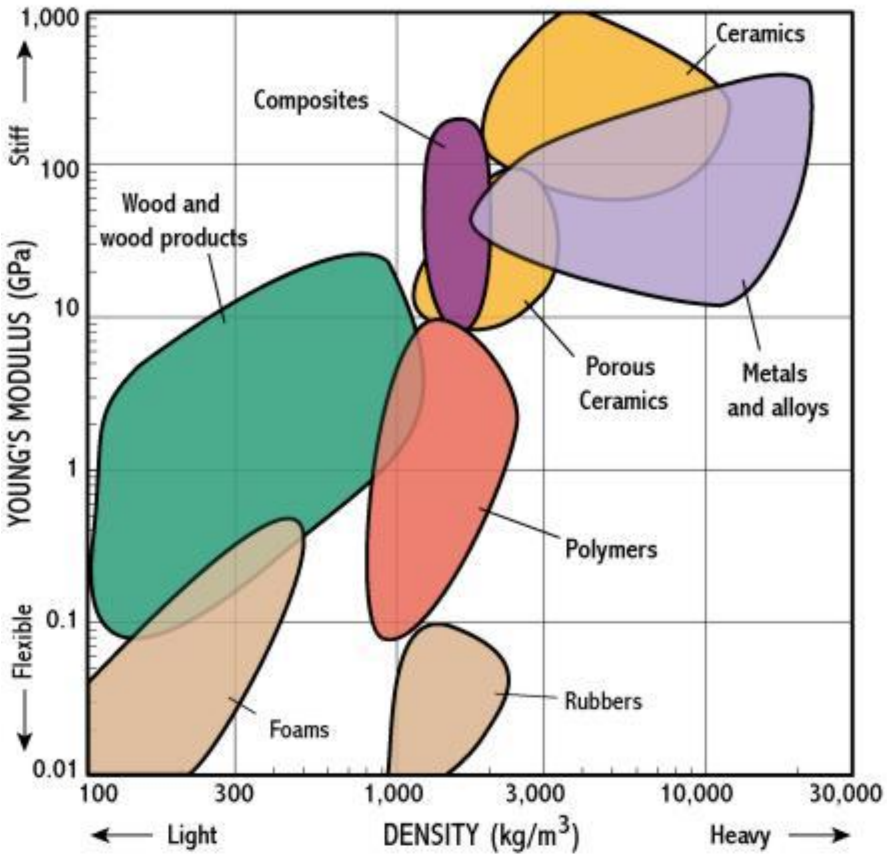


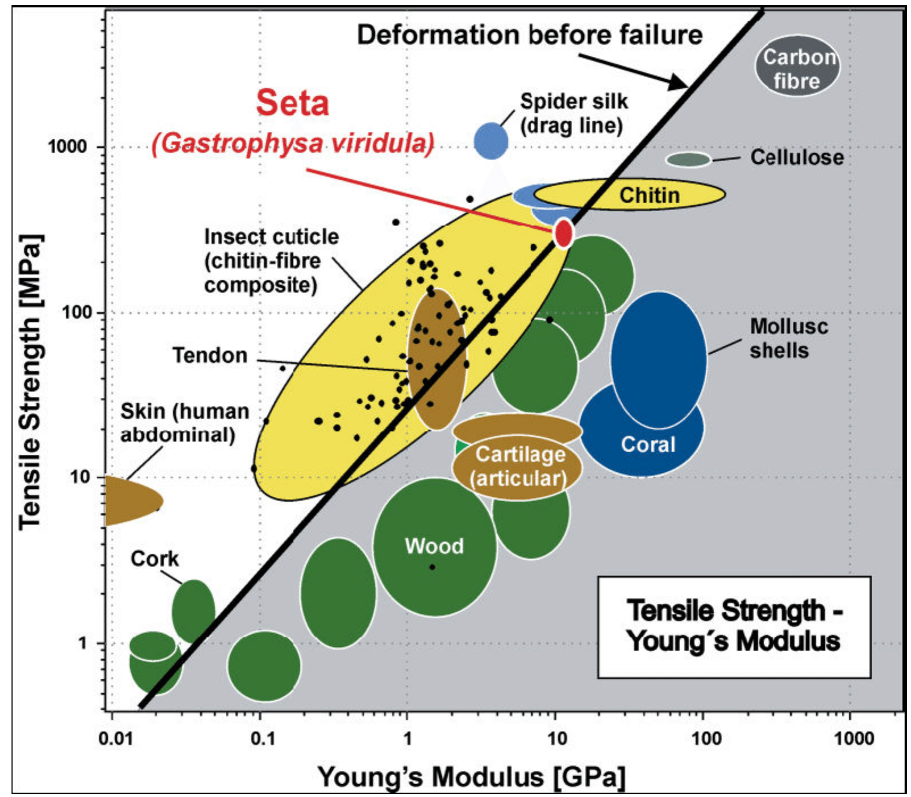
Figure 9.17 The copper–zinc phase diagram. [Adapted from *Binary Alloy Phase Diagrams,* 2nd edition, Vol. 2, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

Deformation mechanism map



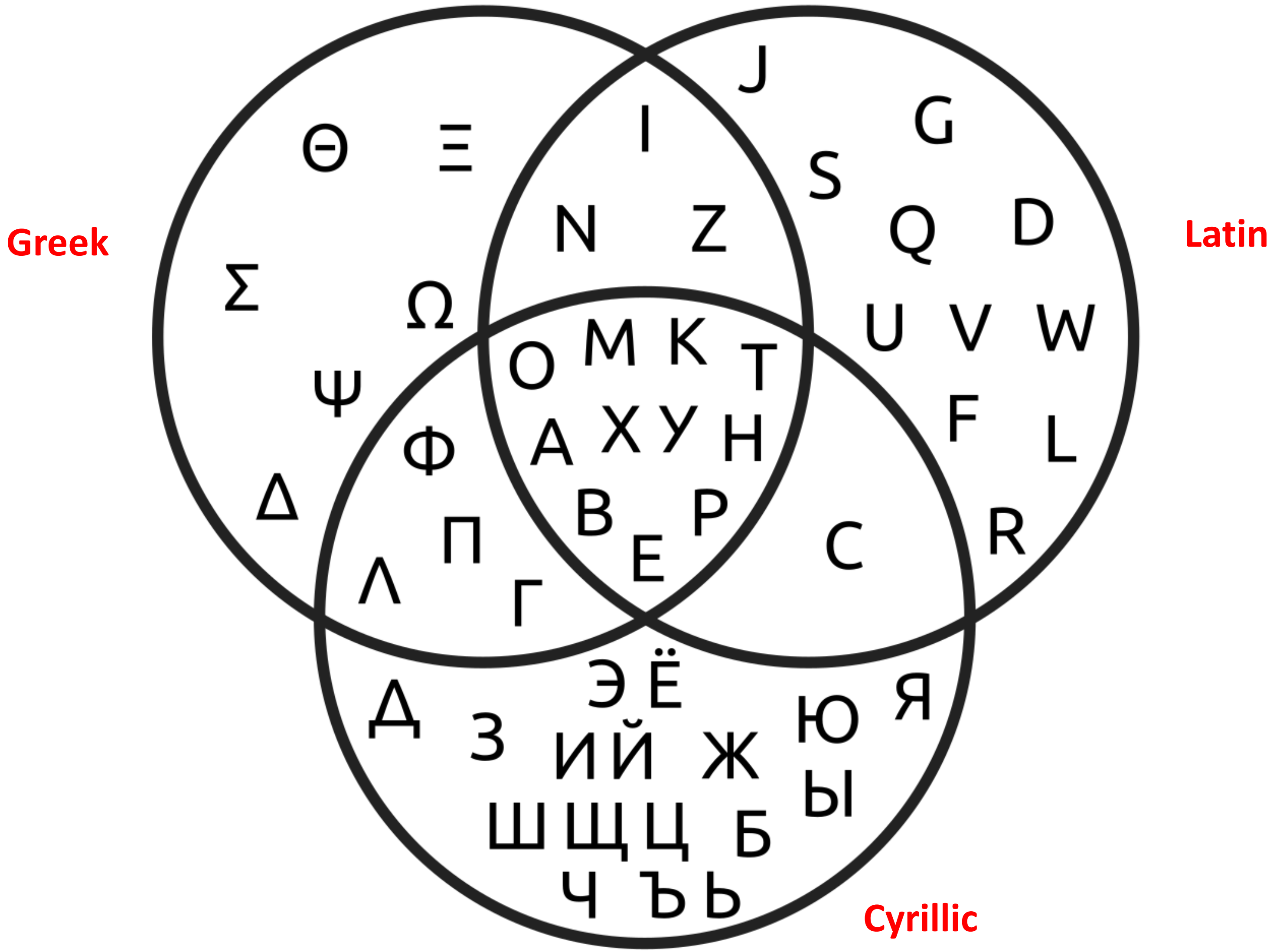


1,000
100
10
1
0.1
0.01
Stiff
Flexible
YOUNG'S MODULUS (GPa)
Ceramics
Composites
Wood and
wood products
Porous
Ceramics
Metals
and alloys
Polymers
Rubbers
Foams
100
300
1,000
3,000
10,000
30,000
Light
DENSITY (kg/m^3)
Heavy



Deformation before failure
Carbon
fibre
Seta
(Gastrophysa viridula)
Spider silk
(drag line)
Cellulose
Chitin
Insect cuticle
(chitin-fibre
composite)
Tendon
Skin (human
abdominal)
Mollusc
shells
Coral
Cartilage
(articular)
Wood
Cork
Tensile Strength -
Young´s Modulus
Tensile Strength [MPa]
1000
100
10
1
0.01
0.1
1
10
100
1000
Young's Modulus [GPa]

Venn diagram



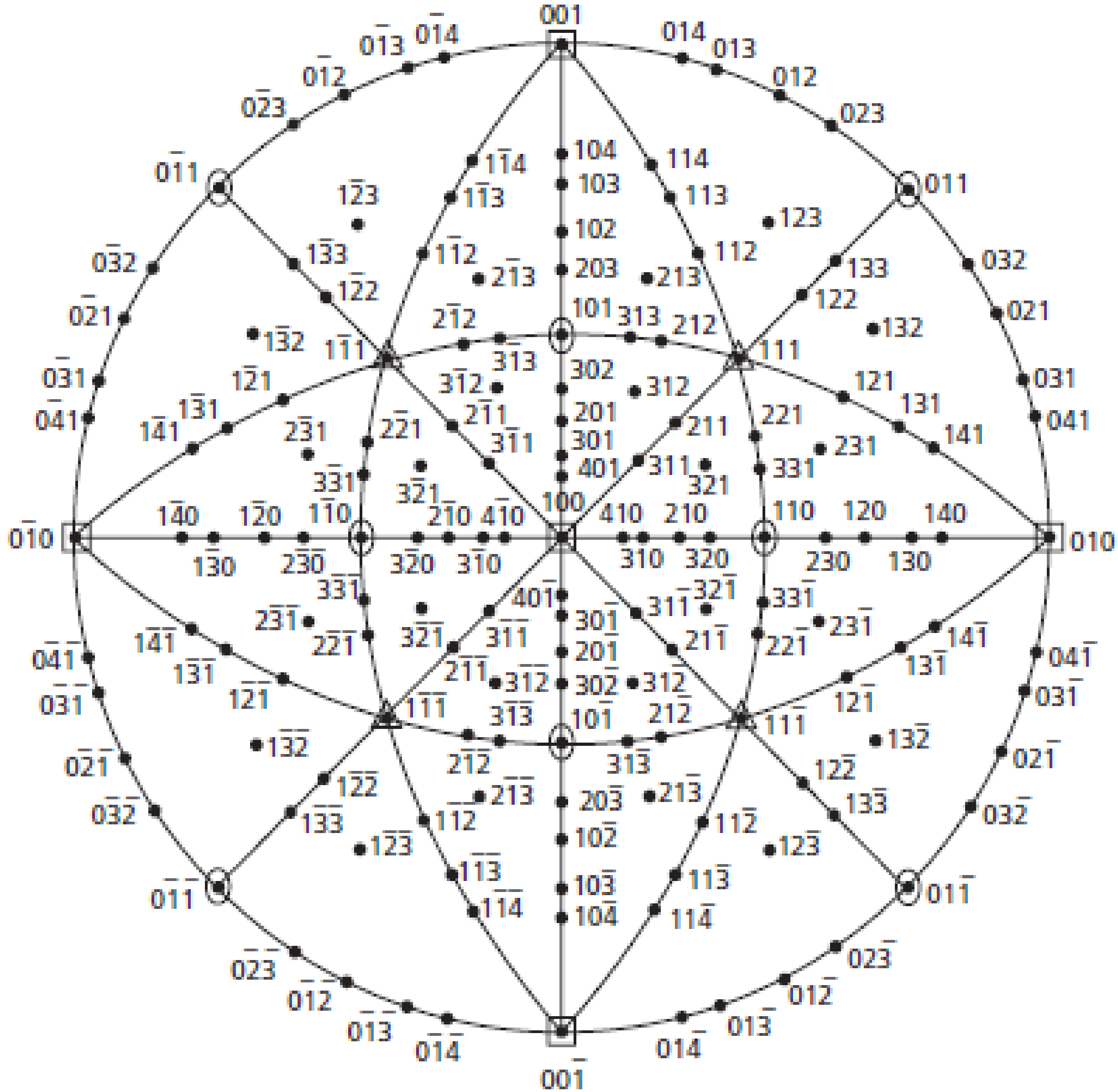


FIG. 1.31 A 100 standard stereographic projection of a cubic crystal showing additional poles

The Design Process

First, a word about types of design. **Original design starts from a genuinely new idea or working principle: the lamp bulb, the telephone, the ball-point pen, the compact disc, the mobile phone.** **More usually, design is adaptive, taking an existing concept and seeking an incremental advance in performance through refinement**.

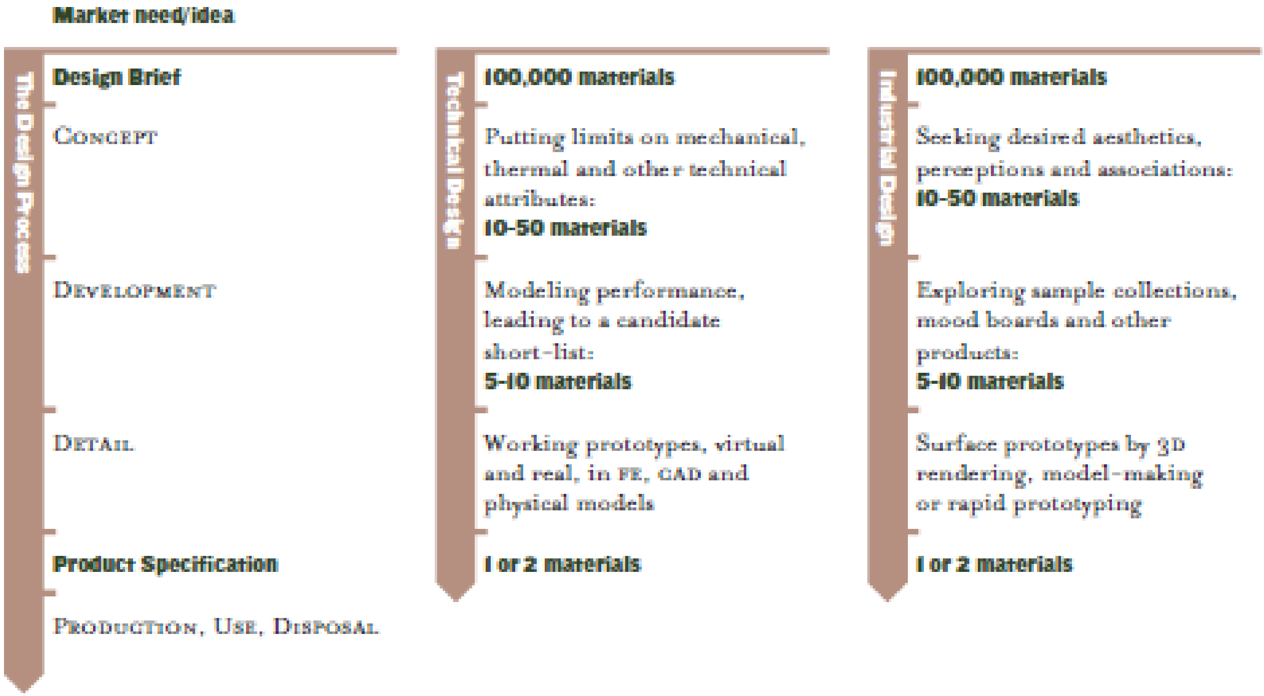
The starting point of a design is a market need or a new idea; **the endpoint is the full specification of a product that fills the need or embodies the idea (3.4).** **It is essential to define the need precisely, that is, to formulate a need statement or design brief, listing product requirements, an expected environment of use and possible consumers.** Writers on design emphasize that the statement should be solution-neutral (that is, it should not imply how the task will be done) to avoid narrow thinking limited by pre-conceptions.

Between the design brief and the final product specification lie many steps. One way of modeling this design process is shown in the left-hand column of 3.4. Design, in this view, has three broad stages: conceptual design, development and detailed design. **The concept presents the way the product will meet the need, the working principle**. Here the designer considers the widest possible range of ideas, both technical and aesthetic. The choice of concept has implications for the overall configuration of the design, but leaves decisions about material and form largely unanswered.

The next stage, development, takes each promising concept and develops it, analyses its operation, and explores alternative choices of material and process that will allow safe operation in the anticipated ranges of loads, temperatures and environments. In parallel with this, alternative forms, colors and textures are explored, seeking, in ways described in Chapter 6, materials and processes capable of creating them.

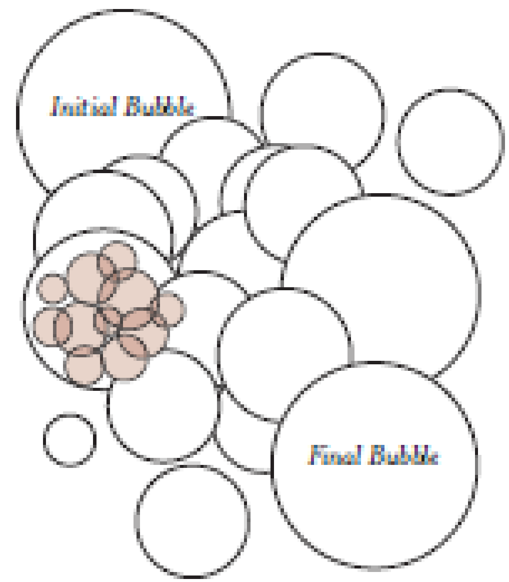
Development ends with a feasible design that is then passed on for detailing. Here specifications for each component are drawn up; critical components are subjected to precise mechanical or thermal analysis; optimization methods are applied to components and groups of components to maximize performance, and costs are analyzed. 3d surface models are used to develop form, and a final choice of geometry, material, manufacturing process and surface is made. The output of this stage is a detailed product specification.

In this way of thinking, materials information is required at each stage of the design (3.4,center and right). The nature of the information needed in the early stages differs greatly in its level of precision and breadth from that needed later on. In conceptual design, the designer requires generic information – broad character sketches – for the widest possible range of materials. All options are open: a polymer may be the best choice for one concept, a metal for another, even though the required function is identical. The need, at this stage, is not for precision; it is for breadth and ease of access: how can the vast range of materials be presented to give the designer the greatest freedom in considering alternatives?



3.4 Materials in the Design Process

The design of a product proceeds from an identification and clarification of the task through concept, development and detailed design to a final product specification. Initially all materials (of which there are perhaps 100,000 in all) are candidates. Technical constraints (center) and constraints of industrial design (right) narrow the choice, leading to a small number that can be explored in detail.



3.5 Bubbles in the Design Process

A bubble analogy for the design process. Adapted from Wallace (1991), in "Research in Design Thinking," a conference at the Technical University of Delft in 1991.

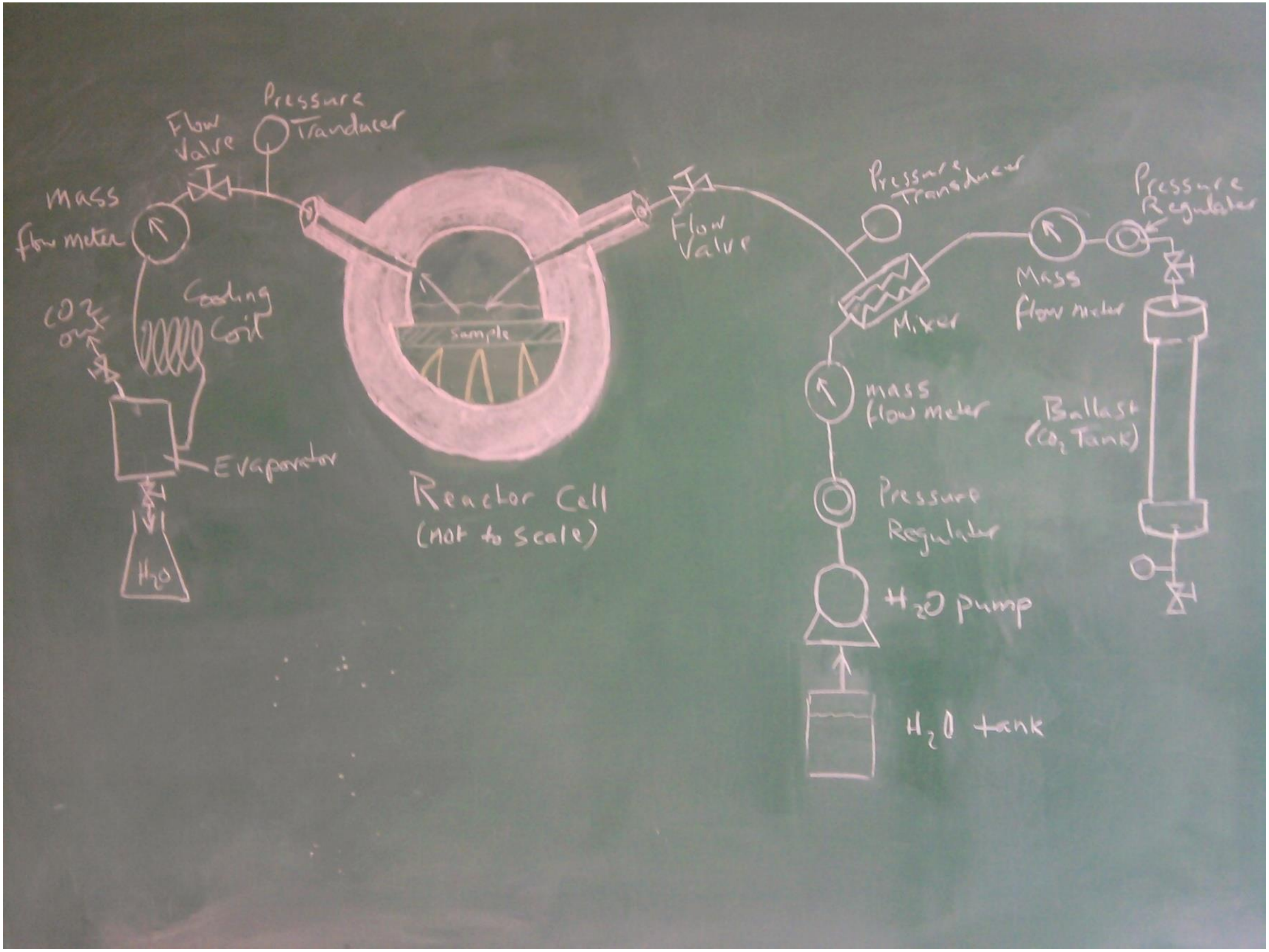
The next step of development requires information for a subset of these materials, but at a higher level of precision and detail. Technical attributes are found in more specialized handbooks and software which deal with a single class of materials and property – corrosion resistance of metals for instance – and allow choice at a level of detail not possible from the broader compilations which include all materials. The material attributes relevant to industrial design are assembled in a different way – ideas gleaned from other designers and products, the study of material collections, the assembly of mood boards, the use of creativity aids, sketching and model-building – we return to all of these in a moment.

The final stage of detailed design requires a still higher level of precision and detail, but for only one or a very few materials – information best found by contacting the material supplier. A given grade of a material (polypropylene, for instance) has a range of properties that derive from differences in the way different suppliers make it. And sometimes even this is not good enough. If the component is a critical one (meaning that its failure could, in some sense or another, be disastrous) then it may be prudent to conduct in-house tests to measure the critical properties, using a sample of the material that will be used to make the product itself. The final step is to make and test full-scale prototypes to ensure that the design meets both the technical and aesthetic expectations of the customer.

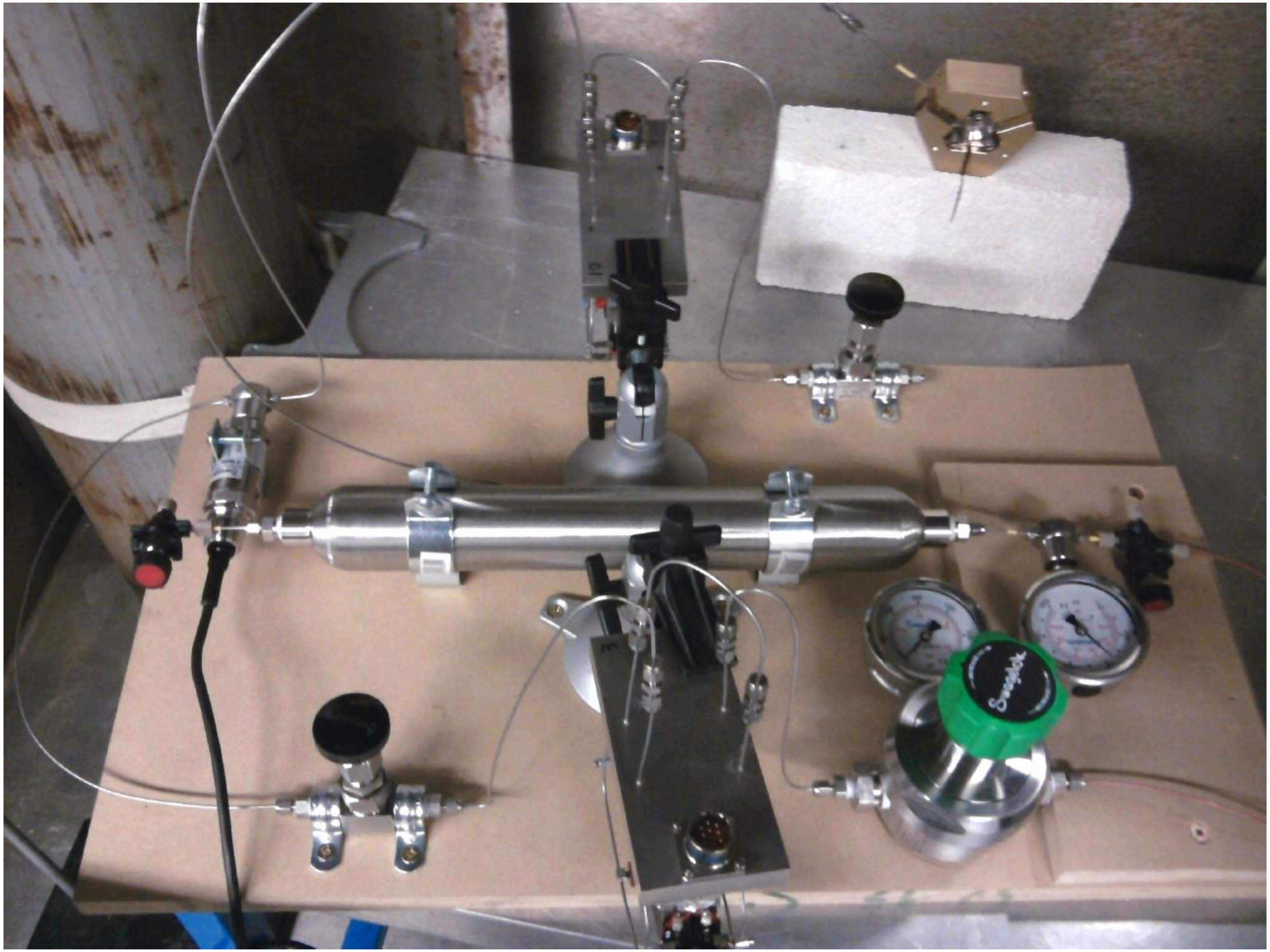
The materials input into design does not end with the establishment of a product specification and final production. Products fail in service, and failures contain information. It is an imprudent manufacturer who does not collect and analyze data on failures. Often this points to the misuse of a material, one which redesign or re-selection can eliminate.

There is much to be said for this structured model of design. Its formality appeals to technical designers, trained in systematic methods for tackling problems of stress analysis or heat flow. But the degree of interdependence in design far exceeds that in stress analysis, so that design requires additional skills, more nearly like those of the experienced lawyer or politician – practiced in assembling and rearranging facts and in judging similarities, differences, probabilities and implications. For design – and particularly for the role of materials in design – this model is perhaps too structured. It does not allow for the variety of paths and influences that lie between the market need and the product specification.

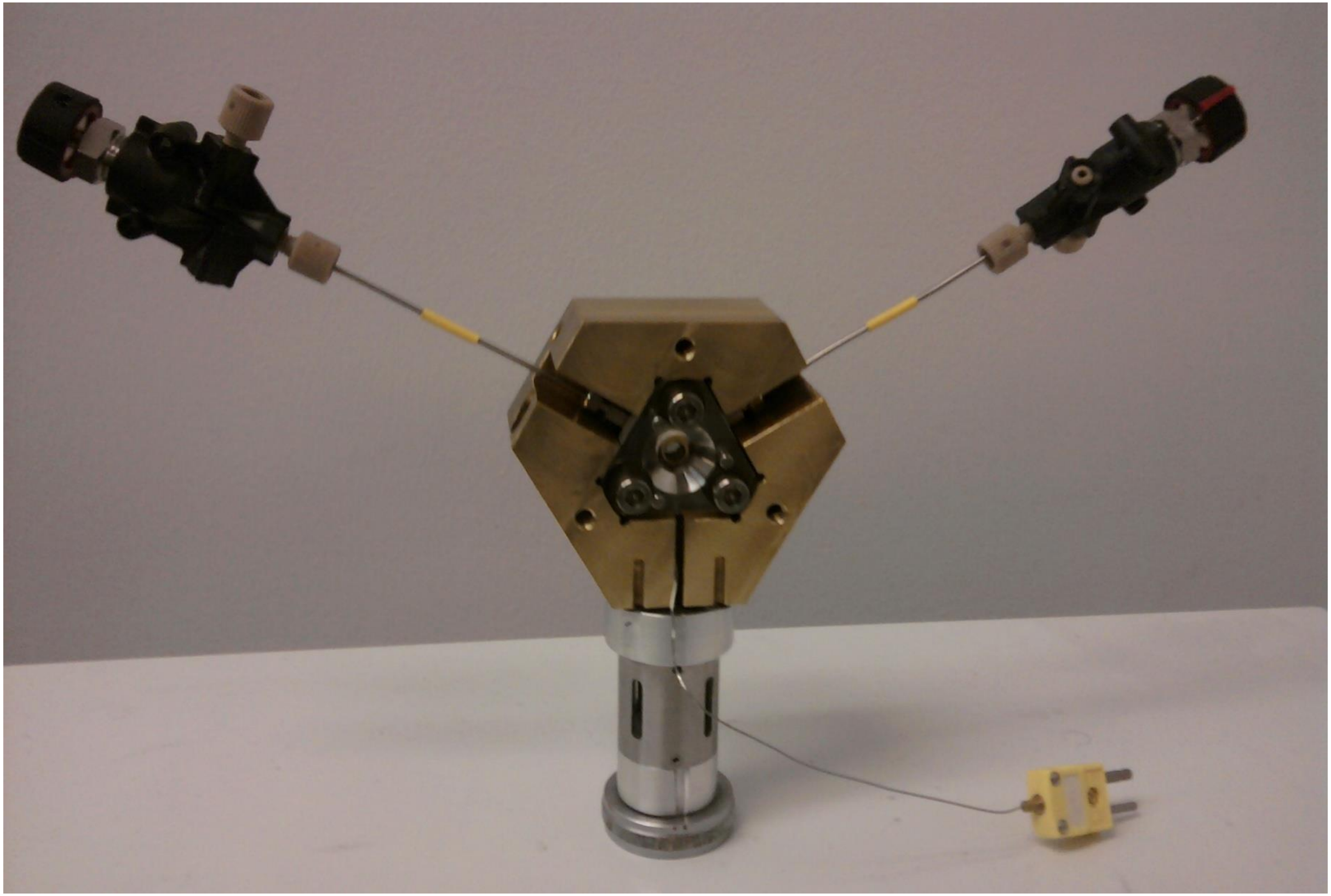
Flow-through micro-reaction system for dynamic & in situ synchrotron X-ray studies

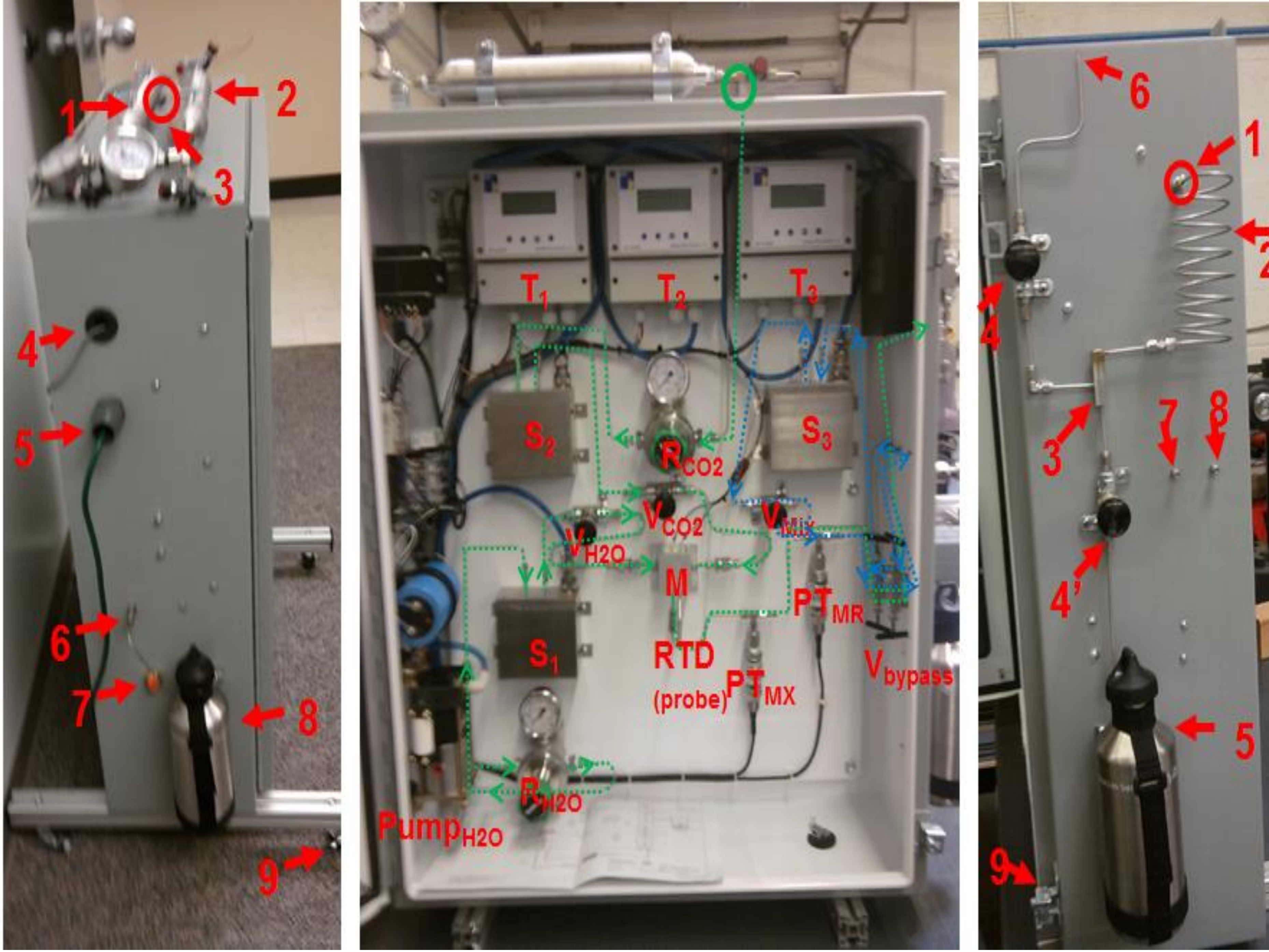


Preliminary Testing



High pressure/high temperature micro-reaction system for in situ synchrotron X-ray flow-through (dynamic) rock/fluid chemical interactions





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T_1
T_2
T_3
S_2
S_3
R_{CO2}
V_{CO2}
V_{H2O}
V_{Mix}
M
PT_{MR}
RTD (probe)
PT_{MX}
V_{bypass}
S_1
R_{H2O}
$Pump_{H2O}$
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