Metallurgy 101 (by popular request)

- Metals are crystalline materials
  - Although electrons are not shared between neighboring atoms in the lattice, the atoms of a metal are effectively covalently bonded.
  - Copper and Aluminum form face centered cubic lattices in their common phase. Iron at low temperature forms a body centered cubic lattice.
  - Although the crystal lattice is a strongly bonded structure it has weak directions relative to crystal planes
    - A single crystal is susceptible to “slip” deformations where crystal planes slide relative to one another.

http://www.astro.virginia.edu/~odf4n/gilbert
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Metallurgy 101 (by popular request)

- Metals are crystalline materials
  - “Real” metals, however, consist of multiple, independent crystalline domains, whose size (and crystalline structure) are temperature history dependent.
- In general, defects = strength
  - defects can arise from
    - empty or contaminated lattice sites
    - dislocations at crystal grain boundaries
      - smaller grains = more boundaries
        = more defects = greater strength

Metallurgy 101 (by popular request)

- Defects and strength
  - At high temperatures atoms are mobile within the lattice (with the extreme being liquifcation)
    - slow cooling (annealing) enables crystalline growth and thus weakens material.
    - “quenching” freezes in fine crystal structure and strengthens a material.
  - Also, at high temperatures, lattice sites become vacant under Maxwell-Boltzmann statistics.
    - quenching can also freeze in these “point” defects thus strengthening the material.
    - similarly, “cold working” (aka “strain hardening”) - deforming the material with stress – can introduce point defects.
      - alloying with small “contaminants has the same effect - e.g. 6061 Al

Mechanical Metallurgy, Dieter
Metallurgy 101 (by popular request)

- Phase diagrams and thermal history
  - Phase diagrams can be quite complex. Internal structure can be manipulated significantly by thermal history.

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Fig. 2.20a. Part of the copper-beryllium system. From *Metals Handbook, ASM*, p. 1176.
Metallurgy 101 (by popular request)

- Phase diagrams and thermal history
  - Aside – P/T phase diagram of water.

http://www.lsbu.ac.uk/water/phase.html
Joining Materials

- **Screws**
  - “English” screws come in standard diameters and thread pitch (threads per inch)
  - Diameters 0, 2, 4, 6, 8, 10, 1/4, 5/16, ....
  - Combined with thread pitch 2-56, 4-40, 6-32, 8-32, 10-24, 1/4-20 are standard sizes.

<table>
<thead>
<tr>
<th>Size (nominal diameter)</th>
<th>Coarse (NC, UNC)</th>
<th>Fine (NF, UNF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Threads per Inch</td>
<td>Tap Drill*</td>
</tr>
<tr>
<td>0 (0.000)</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>1 (0.073)</td>
<td>72</td>
<td>No. 53</td>
</tr>
<tr>
<td>2 (0.096)</td>
<td>72</td>
<td>No. 50</td>
</tr>
<tr>
<td>3 (0.112)</td>
<td>72</td>
<td>No. 47</td>
</tr>
<tr>
<td>4 (0.127)</td>
<td>72</td>
<td>No. 43</td>
</tr>
<tr>
<td>5 (0.159)</td>
<td>40</td>
<td>No. 38</td>
</tr>
<tr>
<td>6 (0.184)</td>
<td>32</td>
<td>No. 29</td>
</tr>
<tr>
<td>8 (0.310)</td>
<td>24</td>
<td>No. 20</td>
</tr>
<tr>
<td>10 (0.195)</td>
<td>24</td>
<td>No. 16</td>
</tr>
<tr>
<td>12 (0.216)</td>
<td>20</td>
<td>No. 14</td>
</tr>
<tr>
<td>1/4</td>
<td>18</td>
<td>No. 3</td>
</tr>
<tr>
<td>5/32</td>
<td>16</td>
<td>No. 7</td>
</tr>
<tr>
<td>3/32</td>
<td>14</td>
<td>No. 5</td>
</tr>
<tr>
<td>7/32</td>
<td>12</td>
<td>No. 4</td>
</tr>
<tr>
<td>9/32</td>
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<td>No. 3</td>
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<tr>
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<td>No. 2</td>
</tr>
<tr>
<td>3/16</td>
<td>8</td>
<td>No. 1</td>
</tr>
</tbody>
</table>

Note: ASA B1.1:1990.
*For approximately 75% thread depth.
Precision placement of components

- Good machining tolerances are 0.001”, however...
  - Screw clear holes have sufficient leeway that screw connected parts do not preserve these tolerances.
  - Assemblies requiring precision relative placement of parts (or repeated disassembly and reassembly) use “pins” or, ideally, “kinematic mounts”
    - Pins are small precision-diameter short stainless steel rods which are press fit into precision-drilled holes providing exact position reference.
    - Kinematic mountings use hard metal surfaces (often pins) to reference (without ambiguity) a part's position.
Kinematic Mountings

- Six variables – (x,y,z) and three rotations – define the orientation of any part.
  - A true kinematic mounting provides exactly six constraints.
  - Kinematic mounts provide for repeatable disassembly and replacement of precision aligned parts.
  - The “cone, groove, and flat” design at right is also robust to thermal expansion of the mount relative to the kinematic part.

Small Parts
Inevitably, instrumentation contains moving parts.
- Smooth, repeatable, friction-free, ... motion is the goal.
- Linear and translational motion must be transmitted by strong, precision torsion and flexure-resistant structures
  - typically use stainless-steel ground shafting
Small Parts – Shafts and Bearings

- Bearings support shafting and permit smooth motion
  - This motion can be both linear and circular
  - Bearings are available in a variety of precisions
    - Bearings are usually paired as the angular constraint of a single bearing is poor.
  - Linear bearings are often incorporated into “slide” assemblies for bulk linear motion
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Small Parts – Gears

- Primary gear functions
  - Provide mechanical (dis)advantage through gear ratio
  - Transmit power through angles (worms, mitres...)

![Image of various gears and goblets]
Small Parts – Gears

- Because of the loose fit between gear components gears are subject to backlash
  - always drive from a single direction ("take up" backlash)
  - use zero-backlash or anti-backlash -or- “preload”
Small Parts – Couplings

- In many cases alignment and separation between shafts cannot be guaranteed.
  - Flexible couplings can take up angular and linear mismatch.
Small Parts – Belt Drives

- Flexible alternative to transmit power.
- No backlash with proper tension.
Not mentioned are a vast range of mounting hardware, precision screws, clips, retainers, bearing mounts, shaft hangers....