

# Flux Method for Preparing Crystals

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*Division of Materials Sciences  
and Engineering*



# Main Group Compounds

| GROUP |    |    |    |    |    |    |    |  |  |  |  |  |  |     |  |  |  |  |  |  |  |
|-------|----|----|----|----|----|----|----|--|--|--|--|--|--|-----|--|--|--|--|--|--|--|
| 1A    |    | 2A |    |    |    |    |    |  |  |  |  |  |  | 13A |  |  |  |  |  |  |  |
| 1     | 2  | 13 | 14 | 15 | 16 | 17 | 18 |  |  |  |  |  |  |     |  |  |  |  |  |  |  |
| H     | He | B  | C  | N  | O  | F  | Ne |  |  |  |  |  |  |     |  |  |  |  |  |  |  |
| Li    | Be | Al | Si | P  | S  | Cl | Ar |  |  |  |  |  |  |     |  |  |  |  |  |  |  |
| Na    | Mg | Ga | Ge | As | Se | Br | Kr |  |  |  |  |  |  |     |  |  |  |  |  |  |  |
| K     | Ca | In | Sn | Sb | Te | I  | Xe |  |  |  |  |  |  |     |  |  |  |  |  |  |  |
| Rb    | Sr | Hg | Tl | Pb | Bi | Po | At |  |  |  |  |  |  |     |  |  |  |  |  |  |  |
| Cs    | Ba | U  | Np | Pu | Am | Cm | Bk |  |  |  |  |  |  |     |  |  |  |  |  |  |  |
| Fr    | Ra | Ac | Th | Pa | U  | Np | Pu |  |  |  |  |  |  |     |  |  |  |  |  |  |  |

## LANTHANIDE

|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 |
| La | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |    |

## ACTINIDE

|    |    |    |    |    |    |    |    |    |    |    |     |     |     |     |     |
|----|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|
| 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 |
| Ac | Th | Pa | U  | Np | Pu | Am | Cm | Bk | Cf | Es | Fm  | Md  | No  | Lr  |     |

## □ Why materials synthesis?

*If you can make samples, then you can pursue the science that appeals to you: Magnetic materials, metals, insulators, superconductors, etc.*

If you know how to cook, you can create what you want.



Pizza



Seafood Stew

## □ Definition of crystal?



*In a crystal, the constituent atoms are arranged in an orderly repeating pattern extending in all three spatial dimensions.*

Spatial extent of the ordered regions (crystallites):

|         |                         |                 |           |
|---------|-------------------------|-----------------|-----------|
| Crystal | poly-/micro-crystalline | nanocrystalline | amorphous |
| ~ mm    | ~ $\mu\text{m}$         | ~ nm            | < nm      |

## □ Why single crystals?

- Aesthetics – gemstones



Ruby

$\text{Al}_2\text{O}_3$   
with  $\sim 1\%$  Cr

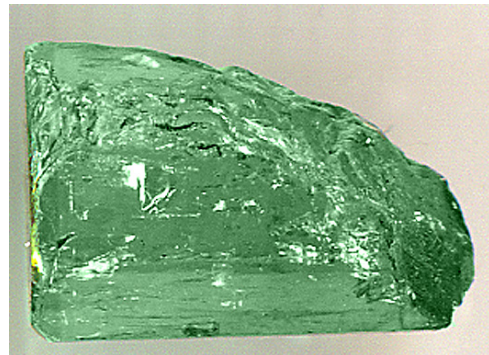


Diamond  
C



Sapphire

$\text{Al}_2\text{O}_3$   
with  $\sim 0.01\%$  Ti & Fe



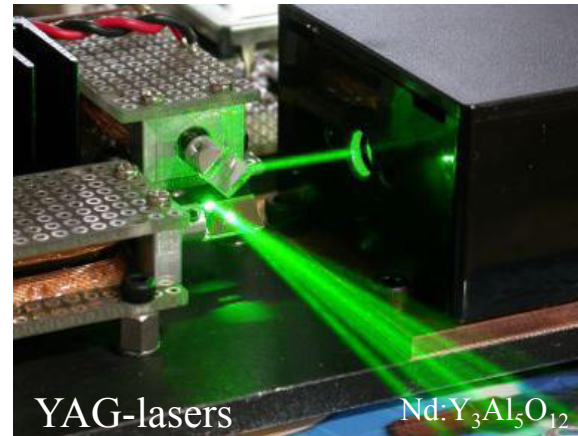
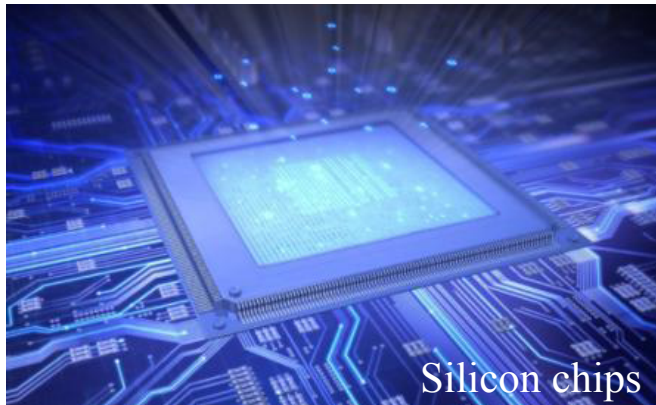
Emerald

$\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$   
With Cr or V dopants

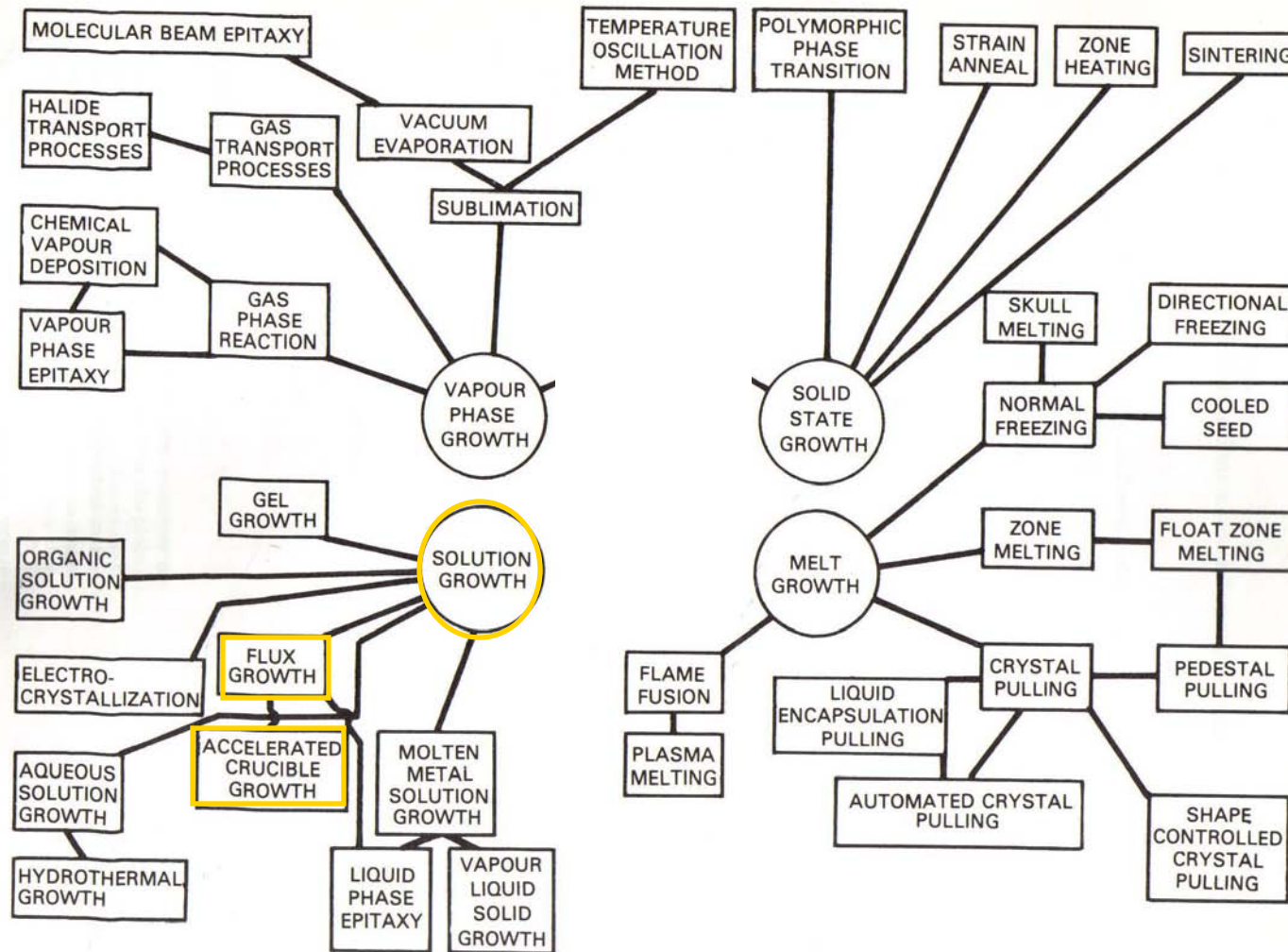


## □ Why single crystals?

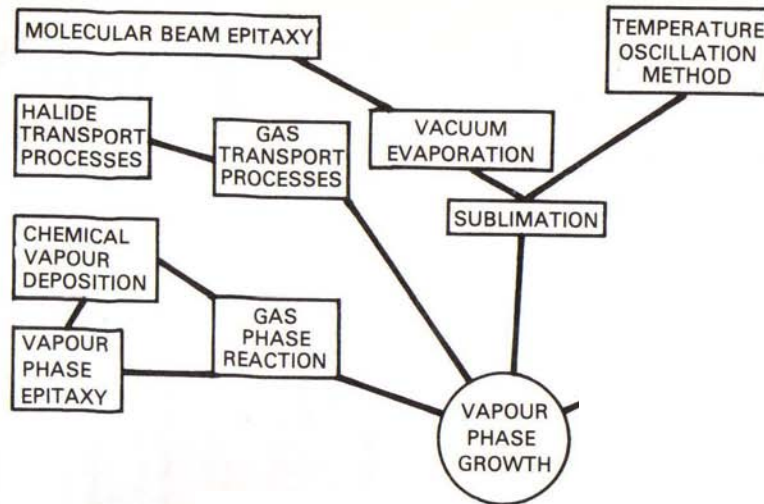
- Find intrinsic properties (no grain boundaries, anisotropic)
- Application in devices



## □ What are the crystal growth techniques?



## □ What are the crystal growth techniques?



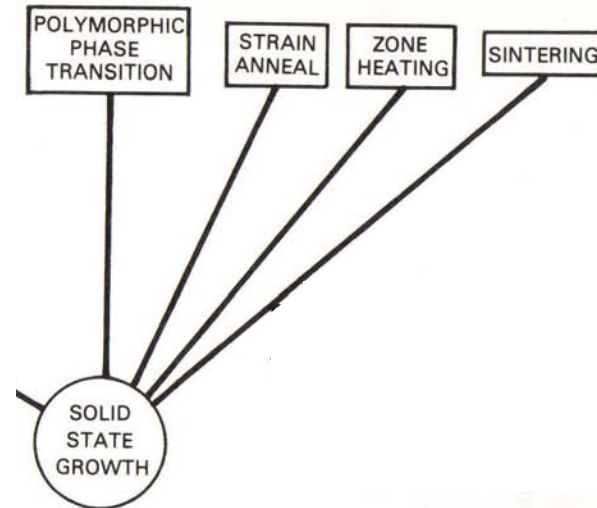
### ***Growth from gas phase – ‘precipitation’ from gas phase***

- solid → gas → xtal
- Chemical vapor transport – need a transport agent
- Pulsed laser deposition – need a substrate or seed

### **Issues:**

- Induce a phase transition – homogeneous gas phase to solid + unsaturated gas
- Control conditions for supersaturation, usually by control of temperature gradients

## □ What are the crystal growth techniques?



### ***Growth from a mixture of solids (no melting)***

- kinetic and thermodynamic factors are important

### **Issues:**

- Crystals are micron size
- Phase segregation, grain boundaries



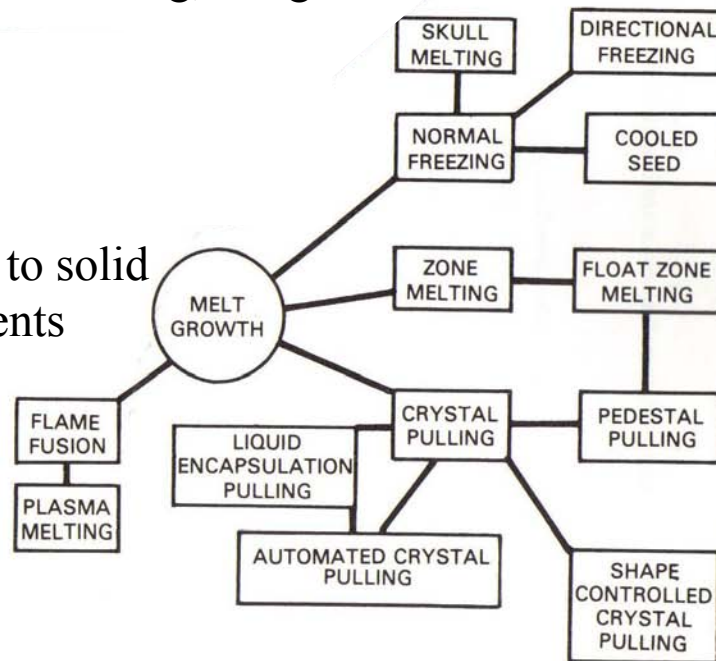
## □ What are the crystal growth techniques?

### *Growth from the liquid phase*

- solid → liquid → solid
- Variations are Bridgman, Czochralski (pulling), Kyropoulos (top seeding), Verneuil (flame fusion), tri-arc, skull melting, image float-zone

### **Issues:**

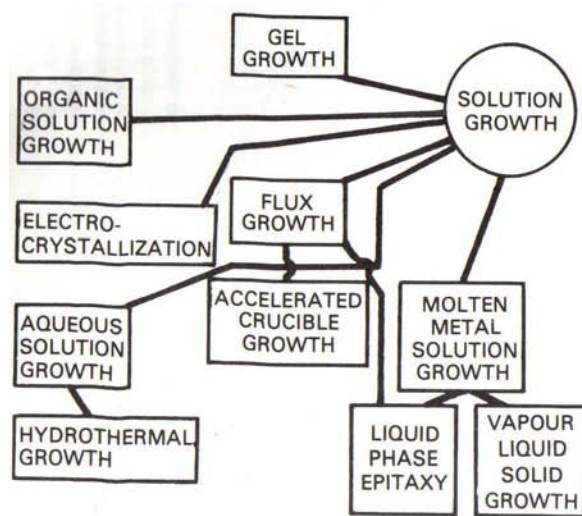
- Induce a phase transition – liquid to solid
- Control of temperature and gradients
- High melting points  $> 2000\text{ }^{\circ}\text{C}$   
(confirmation of melting!)
- Reactivity of crucible
- Control nucleation (seed crystal)



## □ What are the crystal growth techniques?

### *Growth from solution – precipitation from supersaturated solution*

- Aqueous & organic solvents
- Inorganic solvent (flux, high T)
- Hydrothermal (high P & T)



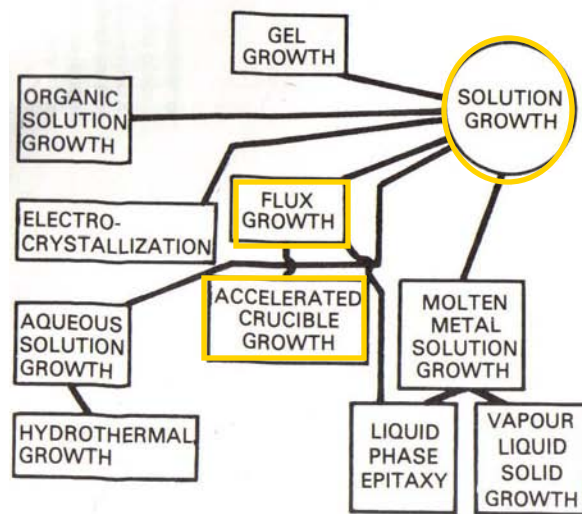
### **Issues:**

- induce a phase transition – homogeneous solution to solid + unsaturated solution
- control conditions for supersaturation– concentration (evaporation of solvent), temperature (solubility or saturation is a function of temperature)
- reactivity of container (crucible)
- inclusion of solvent in crystals

## □ Why solution growth?

### Advantages:

- Grow congruently and incongruently melting materials
- Need relatively simple equipment
- Has short growth-time scales
- Need small amounts of materials



### Disadvantages:

- Not too large a crystal (mm to cm)

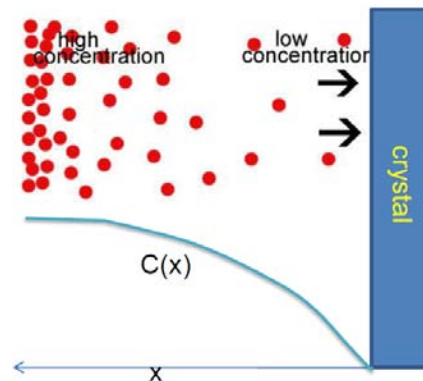
*e.g. Rock candy*



- *Find the right solvent and dissolve the starting materials*

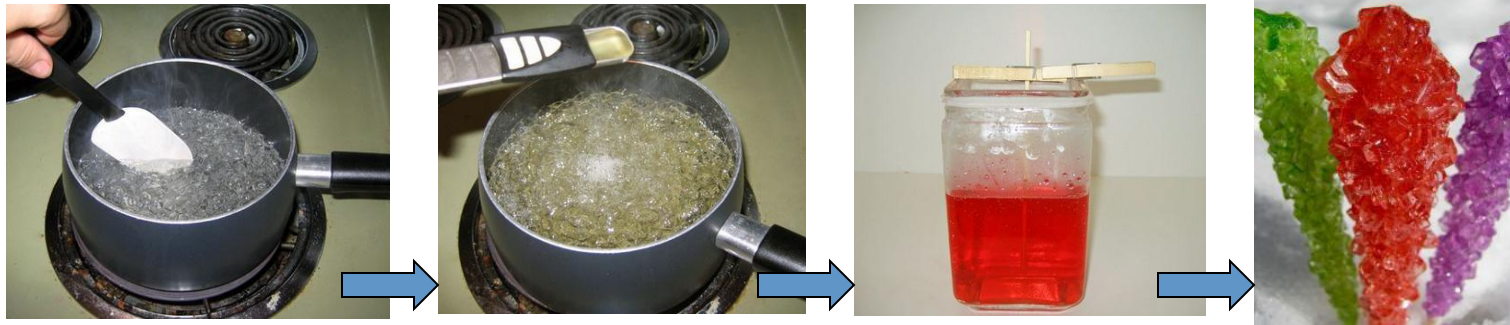
- *Crystallize with time and temperature*

Important: Solvent should have reasonable solubility & Diffusivity





*e.g. Rock candy*



- *Find the right solvent and dissolve the starting materials*

- *Crystallize with time and temperature*

- **Flux Growth** is solution growth at high temperature
- Flux (melt; solvent) can be metals (Ni, Fe, etc.), oxides ( $B_2O_3$ ,  $Bi_2O_3$ ), hydroxides (KOH, NaOH), salts (BaO, PbO,  $PbF_2$ ), eutectic binaries

*e.g. Rock candy*



- *Find the right solvent and dissolve the starting materials*

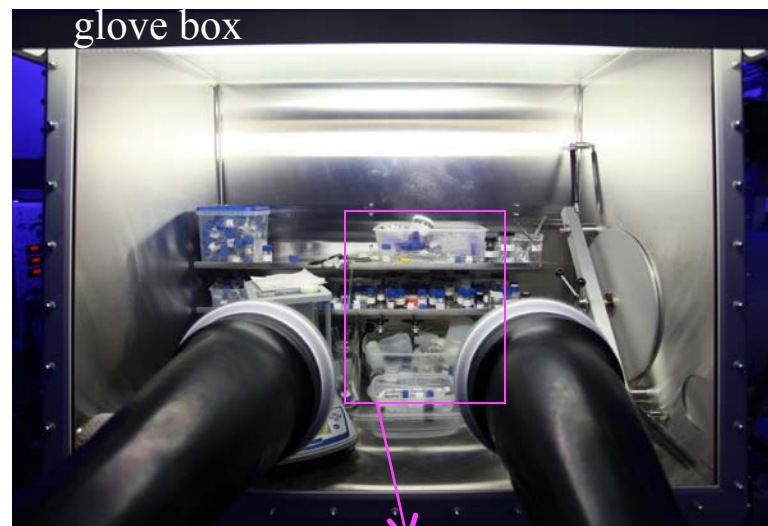
- *Crystallize with time and temperature*

### ***Key characteristics for fluxes***

- Have low melting temperature
- Be easily separated from the products
- Not form stable compounds with the reactants
- Have a large difference between boiling & melting temp.

## □ What are flux growth needs?

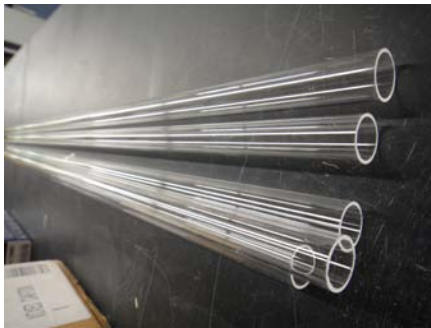
- Elements
- Cutting tools



## □ What are flux growth needs?



- Crucibles
- Tubes (reaction under ambient conditions not possible)



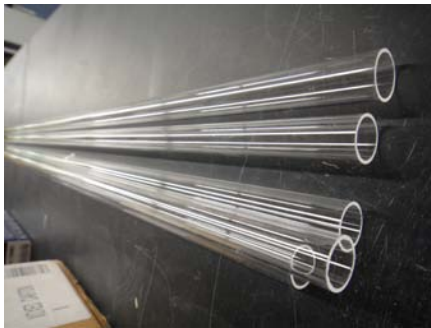
|                                     | $T_{\text{max}}$ (°C) | $T_{\text{melting}}$ (°C) |
|-------------------------------------|-----------------------|---------------------------|
| borosilicate glass (Pyrex)          | 515                   | 820                       |
| gold                                | 1013                  | 1064                      |
| silica (quartz)                     | 1200                  | 1853                      |
| platinum                            | 1720                  | 1770                      |
| alumina ( $\text{Al}_2\text{O}_3$ ) | 1900                  | 2072                      |
| zirconia ( $\text{ZrO}_2$ )         | 2000                  | 2700                      |
| magnesia ( $\text{MgO}$ )           | 2400                  | 2852                      |
| tantalum                            | 1400                  | 3017                      |



## □ What are flux growth needs?



- Crucibles
- Tubes (reaction under ambient conditions not possible)



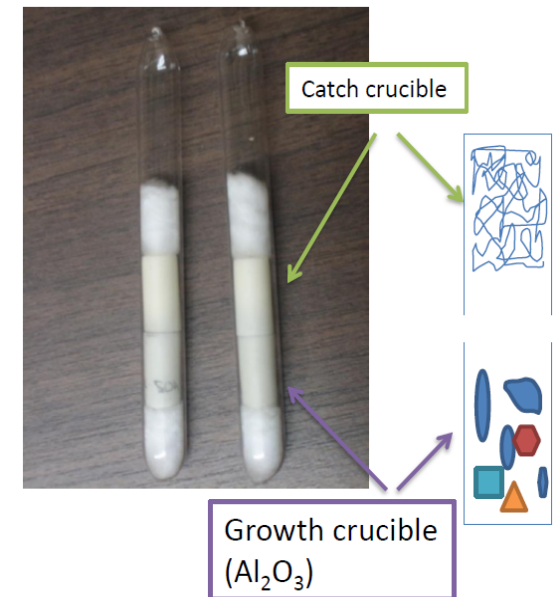
### Elements

### Container & tube choices

|                                |   |
|--------------------------------|---|
| Alkali & alkaline-earth metals | Ta, steel   |
| Al, Ga                         | $\text{Al}_2\text{O}_3$ , MgO, BeO                  |
| Mg                             | MgO, Ta, graphite or steel                          |
| Cu, Ag, Au                     | graphite, MgO, $\text{Al}_2\text{O}_3$ , Ta         |
| Fe, Co, Ni                     | $\text{Al}_2\text{O}_3$ , $\text{ZrO}_2$            |
| Zn, Cd, Hg                     | $\text{Al}_2\text{O}_3$                             |
| In                             | $\text{Al}_2\text{O}_3$ , Ta                        |
| Rare-earth metals              | Ta, Mo, W, BeO                                      |
| Bi, Sn                         | $\text{Al}_2\text{O}_3$ , $\text{SiO}_2$ , graphite |
| Sb                             | $\text{SiO}_2$ , graphite                           |

## □ What are flux growth needs?

- Arc melt
- Glass sealing station



## □ What are flux growth needs?

### - Furnaces



SiC heating elements ( $T_{\text{max}} = 1500\text{ }^{\circ}\text{C}$ )

MoSi<sub>2</sub> heating elements ( $T_{\text{max}} = 1700\text{ }^{\circ}\text{C}$ )

## □ What are flux growth needs?

- Centrifuges

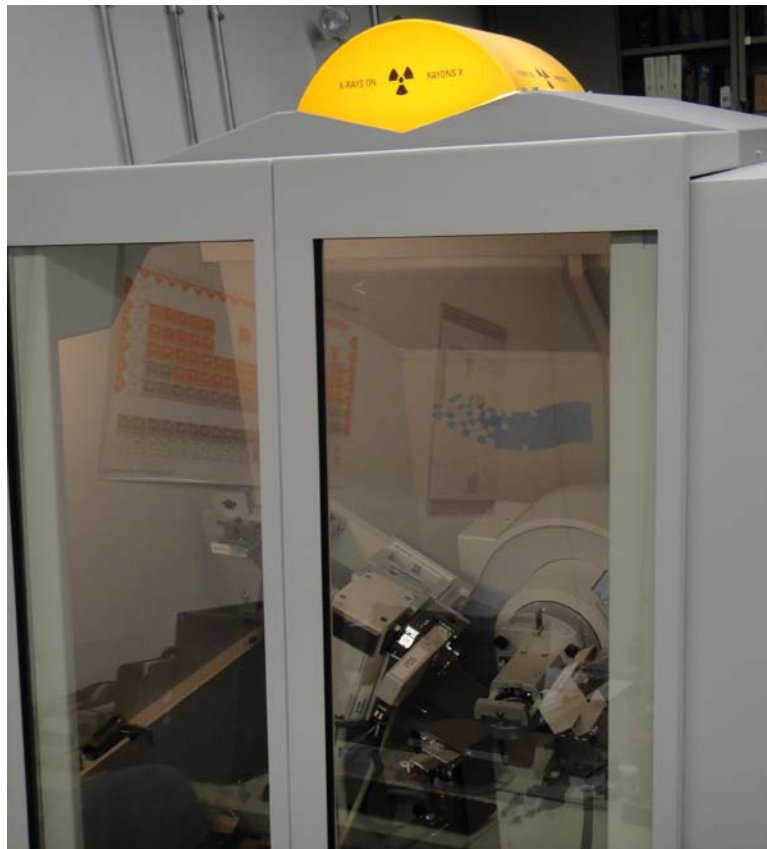


- Chemical etchers (e.g. for Al, use NaOH; for Ga or In, use HCl)
- Mechanical removal tools



## □ What are flux growth needs?

- Energy dispersive spectrometer
- X-ray diffractometer (powder or single crystal)



## □ Where to start?

### ❖ (1) Review basic literature on flux growth

#### **Growth of single crystals from molten metal fluxes**

Fisk, Z. and Remeika, JP

Gschneidner Jr, KA and Eyring, L. (eds) (1989)  
*Handbook on the Physics and Chemistry of Rare Earths*  
12, p. 53. Elsevier, Amsterdam

PHILOSOPHICAL MAGAZINE B, 1992, VOL. 65, No. 6, 1117–1123

#### **Growth of single crystals from metallic fluxes**

By P. C. CANFIELD and Z. FISK

Los Alamos National Laboratory,  
Los Alamos, New Mexico 87545, USA

#### **The Design, Discovery, Growth and Physical Properties of Novel Intermetallic Compounds**



Paul C. Canfield



#### **The Metal Flux: A Preparative Tool for the Exploration of Intermetallic Compounds**

*Mercouri G. Kanatzidis,\* Rainer Pöttgen,\* and Wolfgang Jeitschko\**

#### **Introduction to Techniques for Crystal Growth or In the Age of Nano, Why Bother to Grow Crystals?**

J.E. Greedan, BIMR McMaster University

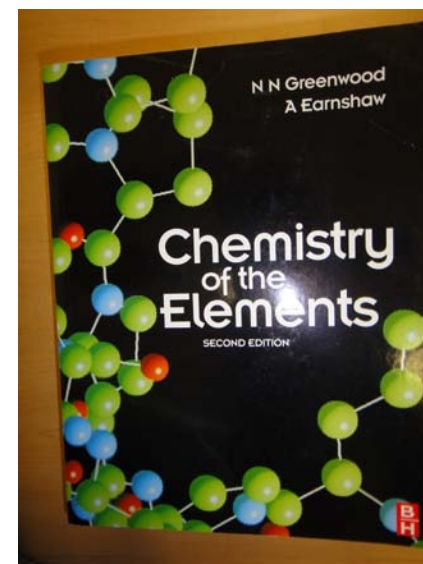


## □ Where to start?

### ❖ (2) Learn about the elements

e.g. reactivity, toxicity, general properties

Atmosphere control may be crucial –  
i.e. samples can't be made in air!



*‘Wikipedia’ descriptions...*

**La:** *“forms a hydrated oxide with moisture in air*

**Na:** *“burns with a yellow flame; reacts violently with water, oxidizes in air”*

**K:** *“oxidizes rapidly in air; very reactive with water; burns in contact with skin”*

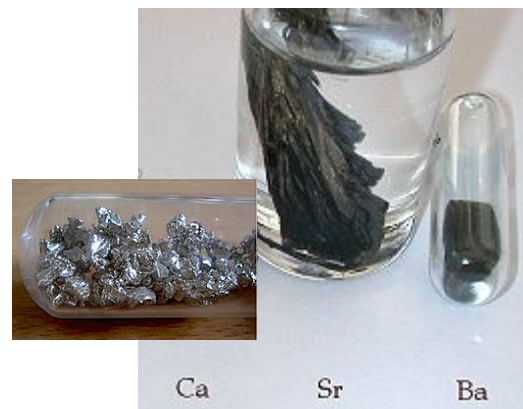
**Ba:** *“reacts exothermically with oxygen, & violently with water”*

**P:** *“high reactivity; widely used in explosives, nerve agents, friction matches, fireworks”*

**As:** *“poisonous”; “frequently used for murder...”*

□ Where to start?

❖ (2) Learn about the elements



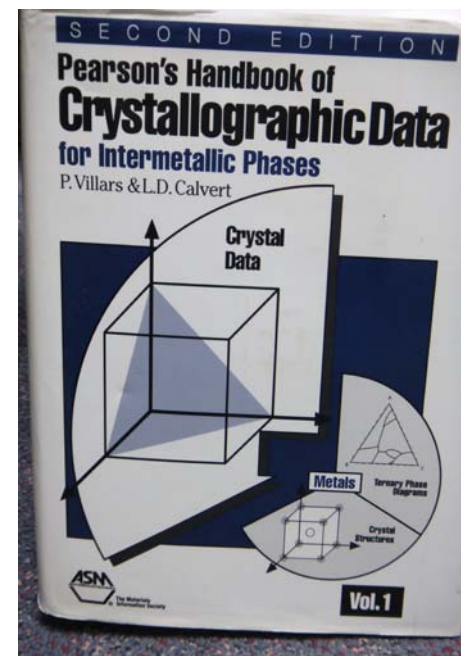
|                                    |                                    |                                     |                                     |                                    |                                     |                                     |                                     |                                   |                                     |                                  |    |
|------------------------------------|------------------------------------|-------------------------------------|-------------------------------------|------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-----------------------------------|-------------------------------------|----------------------------------|----|
| 19 39.098<br><b>K</b><br>POTASSIUM | 20 40.078<br><b>Ca</b><br>CALCIUM  | 21 44.956<br><b>Sc</b><br>SCANDIUM  | 22 47.867<br><b>Ti</b><br>TITANIUM  | 23 50.942<br><b>V</b><br>VANADIUM  | 24 51.996<br><b>Cr</b><br>CHROMIUM  | 25 54.938<br><b>Mn</b><br>MANGANESE | 26 55.845<br><b>Fe</b><br>IRON      | 27 58.933<br><b>Co</b><br>COBALT  | 28 58.693<br><b>Ni</b><br>NICKEL    | 29 63.546<br><b>Cu</b><br>COPPER | 30 |
| 37 85.468<br><b>Rb</b><br>RUBIDIUM | 38 87.62<br><b>Sr</b><br>STRONTIUM | 39 88.906<br><b>Y</b><br>YTTRIUM    | 40 91.224<br><b>Zr</b><br>ZIRCONIUM | 41 92.906<br><b>Nb</b><br>NIOBIUM  | 42 95.94<br><b>Mo</b><br>MOLYBDENUM | 43 (98)<br><b>Tc</b><br>TECHNETIUM  | 44 101.07<br><b>Ru</b><br>RUTHENIUM | 45 102.91<br><b>Rh</b><br>RHODIUM | 46 106.42<br><b>Pd</b><br>PALLADIUM | 47 107.87<br><b>Ag</b><br>SILVER | 48 |
| 55 132.91<br><b>Cs</b><br>CAESIUM  | 56 137.33<br><b>Ba</b><br>BARIUM   | 57-71<br><b>La-Lu</b><br>Lanthanide | 72 178.49<br><b>Hf</b><br>HAFNIUM   | 73 180.95<br><b>Ta</b><br>TANTALUM | 74 183.84<br><b>W</b><br>TUNGSTEN   | 75 186.21<br><b>Re</b><br>RHENIUM   | 76 190.23<br><b>Os</b><br>OSMIUM    | 77 192.22<br><b>Ir</b><br>IRIDIUM | 78 195.08<br><b>Pt</b><br>PLATINUM  | 79 196.97<br><b>Au</b><br>GOLD   | 80 |

|    | IE (kJ/mol) | metal radius (pm) | T <sub>melt</sub> (°C) | T <sub>boil</sub> (°C) | D <sub>20°C</sub> (g/cm <sup>3</sup> ) |
|----|-------------|-------------------|------------------------|------------------------|--|
| Ca | 590         | 197               | 842                    | 1494                   | 1.55                                   |
| Sr | 550         | 215               | 769                    | 1382                   | 2.63                                   |
| Ba | 503         | 222               | 729                    | 1805                   | 3.59                                   |

## □ Where to start?

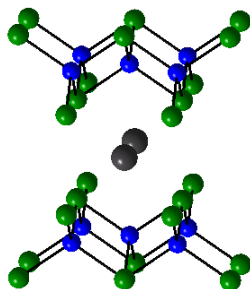
### ❖ (3) Find structure data

Same structure-types may give similar physical properties!



e.g. Fe-based superconductor ( $\text{BaFe}_{1.84}\text{Co}_{0.16}\text{As}_2$ ) has  $\text{ThCr}_2\text{Si}_2$  structure.

Explore other Fe-based compounds with this structure:



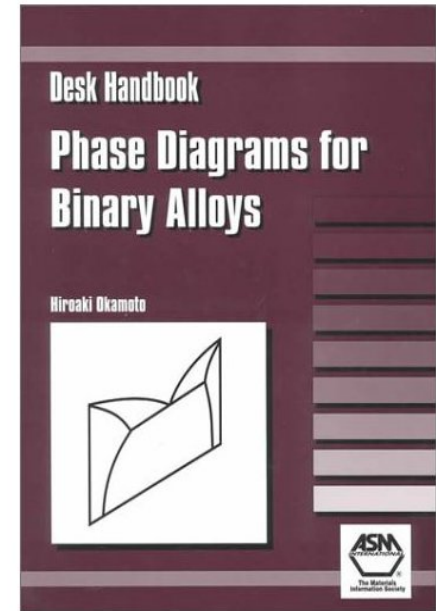
|                            |                            |                            |                            |                            |                            |                            |                            |
|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| $\text{EuFe}_2\text{As}_2$ | $\text{KFe}_2\text{As}_2$  | $\text{BaFe}_2\text{As}_2$ | $\text{SrFe}_2\text{As}_2$ | $\text{DyFe}_2\text{B}_2$  | $\text{HoFe}_2\text{B}_2$  | $\text{TmFe}_2\text{B}_2$  | $\text{BaFe}_2\text{P}_2$  |
| $\text{CaFe}_2\text{P}_2$  | $\text{CeFe}_2\text{Ge}_2$ | $\text{ErFe}_2\text{B}_2$  | $\text{LuFe}_2\text{B}_2$  | $\text{YFe}_2\text{B}_2$   | $\text{CeFe}_2\text{P}_2$  | $\text{GdFe}_2\text{B}_2$  | $\text{TbFe}_2\text{B}_2$  |
| $\text{CeFe}_2\text{Si}_2$ | $\text{DyFe}_2\text{Si}_2$ | $\text{ErFe}_2\text{Ge}_2$ | $\text{EuFe}_2\text{P}_2$  | $\text{DyFe}_2\text{Ge}_2$ | $\text{ErFe}_2\text{Si}_2$ | $\text{EuFe}_2\text{Si}_2$ | $\text{LaFe}_2\text{Ge}_2$ |
| $\text{LaFe}_2\text{P}_2$  | $\text{SmFe}_2\text{Ge}_2$ | $\text{UFe}_2\text{Ge}_2$  | $\text{LaFe}_2\text{Si}_2$ | $\text{NdFe}_2\text{Si}_2$ | $\text{TlFe}_2\text{Se}_2$ | $\text{ThFe}_2\text{Si}_2$ | $\text{YFe}_2\text{Si}_2$  |
| $\text{UFe}_2\text{P}_2$   | $\text{GdFe}_2\text{Ge}_2$ | $\text{NdFe}_2\text{Ge}_2$ | $\text{TbFe}_2\text{Ge}_2$ | $\text{YbFe}_2\text{Ge}_2$ | $\text{LuFe}_2\text{Si}_2$ | $\text{PrFe}_2\text{Si}_2$ | $\text{SmFe}_2\text{Si}_2$ |
| $\text{TmFe}_2\text{Si}_2$ | $\text{YbFe}_2\text{Si}_2$ | $\text{PrFe}_2\text{Ge}_2$ | $\text{ThFe}_2\text{Ge}_2$ | $\text{HoFe}_2\text{Si}_2$ | $\text{SrFe}_2\text{P}_2$  | $\text{TbFe}_2\text{Si}_2$ | $\text{TlFe}_2\text{S}_2$  |
| $\text{UFe}_2\text{Si}_2$  | $\text{ZrFe}_2\text{Si}_2$ | . . .                      |                            |                            |                            |                            |                            |



## □ Where to start?

### ❖ (4) Find the existing phase diagrams

- Binary diagrams are a good start (may be your only option)
- Ternary, quaternary growths generally involve educated guesses.

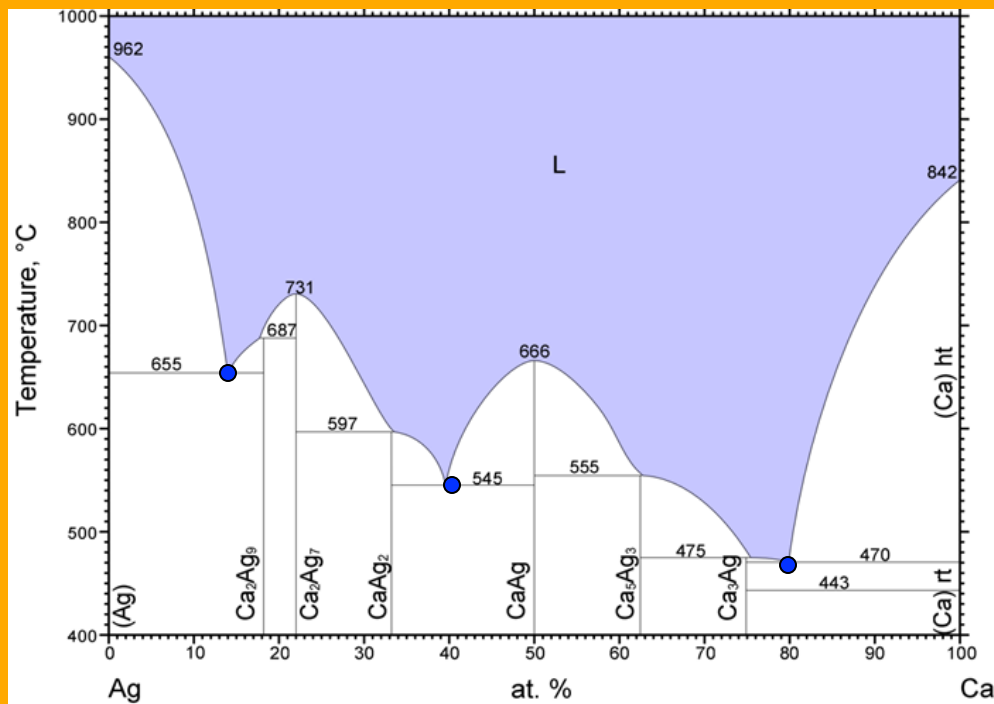


*Let's review a few binary phase diagrams*

**Ca-Ag**  
**Ba-Ag**

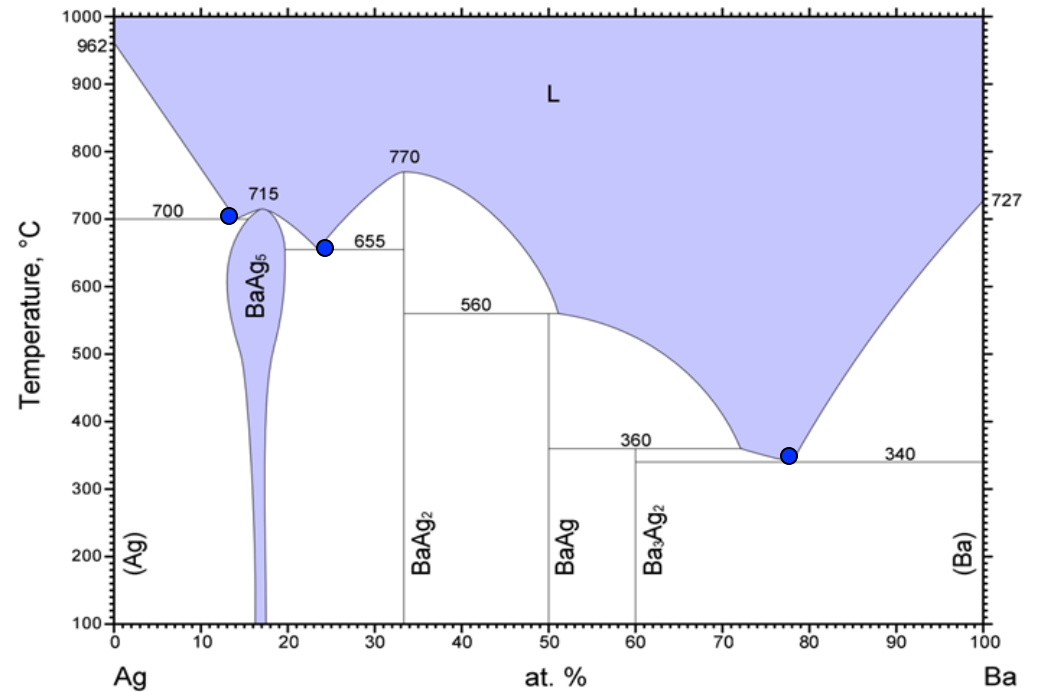
|                                    |                                    |                                     |                                     |                                    |                                     |                                     |                                     |                                   |                                     |                                  |
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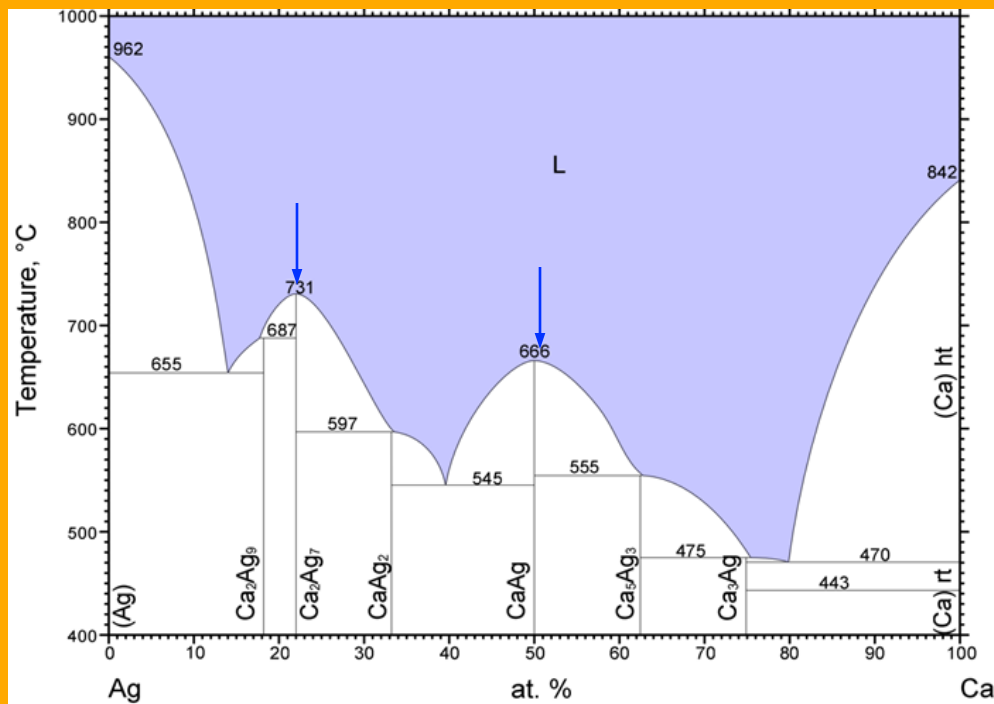
*...detour*



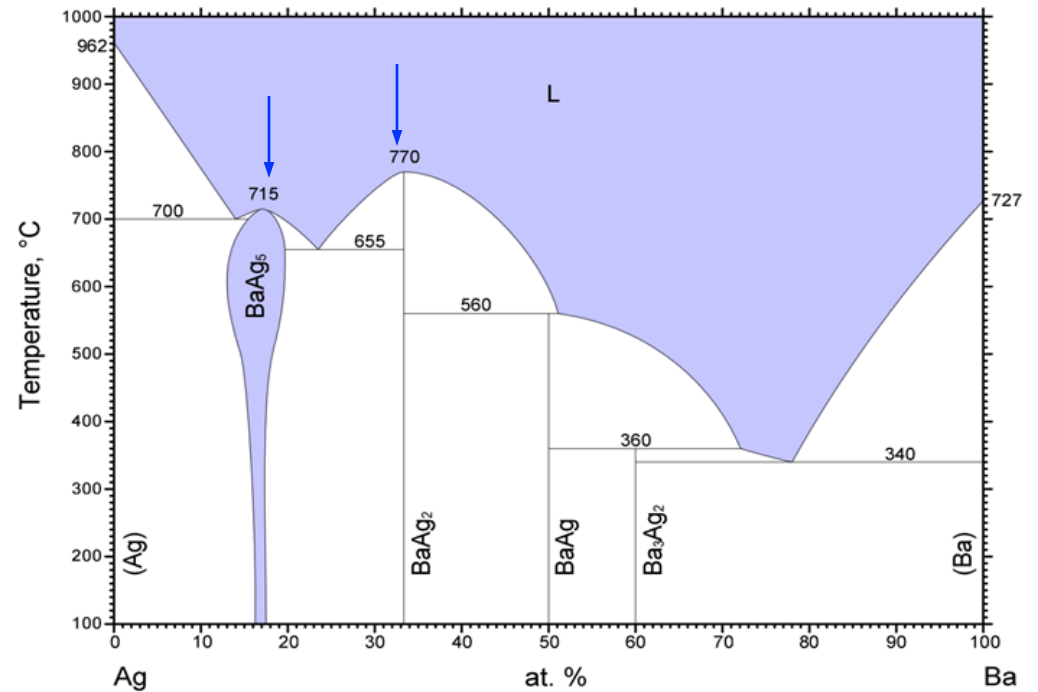
## Eutectic point:

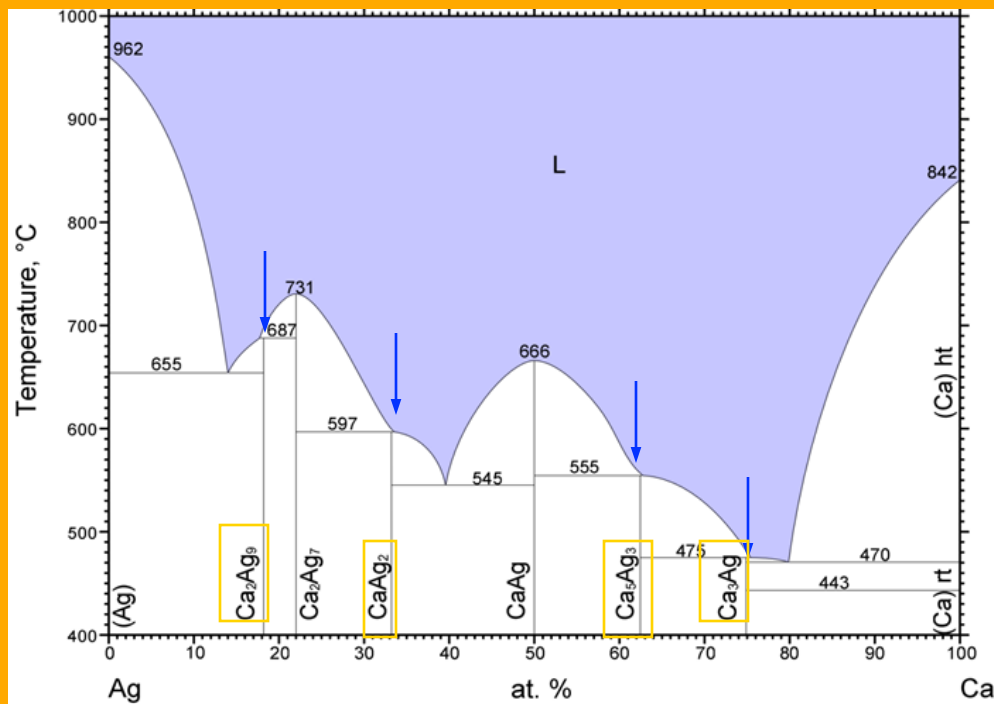
- Minima in liquid region
- Easily accessible liquid region





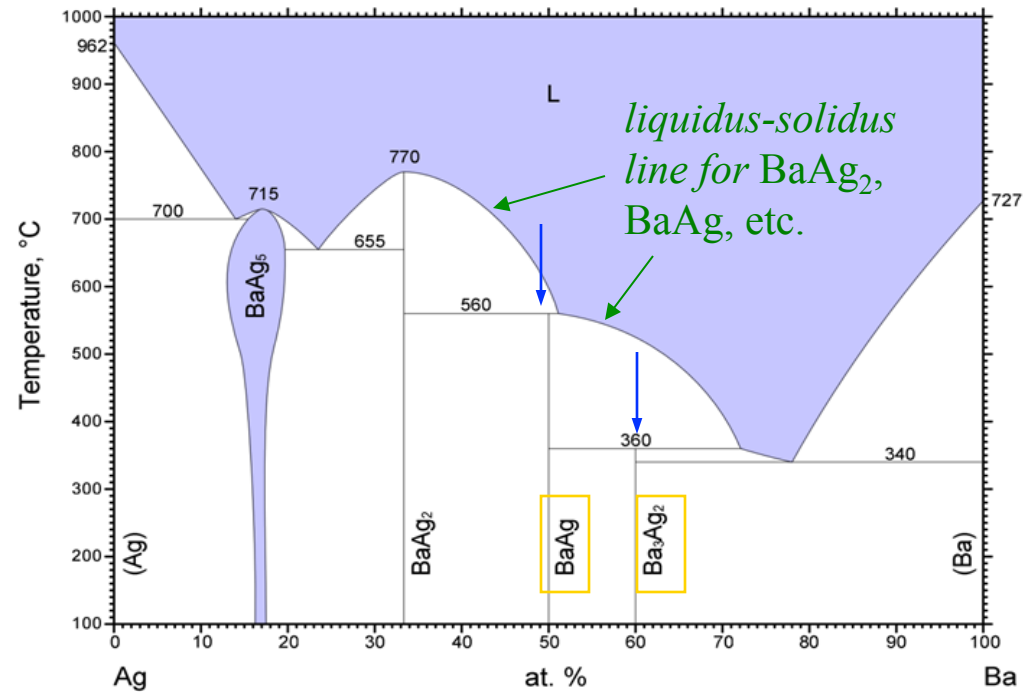
**Congruent reaction:**  
Transformation from a homogeneous liquid to a homogenous solid





## Peritectic reaction:

- Melt incongruently, i.e. decompose into a mixed solid and a liquid phase



## □ Where to start?

### ❖ (5) Find a good metallic flux for crystal growth

A good flux (a) has a low melting temperature,  
 (b) has a good solubility for the elements,  
 (c) does not enter crystal as inclusions, &  
 (d) does not create competing phases, etc.

|                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|----------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|-------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|-------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|-------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|-------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|-------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|-------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|----------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
| 1 I A                        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 II A                       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 13 III A                        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 14 IV A                          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 15 VA                        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 16 VIA                        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 17 VII A                     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 18 VIII A                     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 1.0079<br>H<br>HYDROGEN    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 4.0026<br>He<br>HELIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 6.941<br>Li<br>LITHIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 4 9.0122<br>Be<br>BERYLLIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 10.811<br>B<br>BORON           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 6 12.011<br>C<br>CARBON      |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 7 14.007<br>N<br>NITROGEN     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 15.999<br>O<br>OXYGEN      |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 18.998<br>F<br>FLUORINE     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 20.180<br>Ne<br>NEON       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 11 22.990<br>Na<br>SODIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 12 24.305<br>Mg<br>MAGNESIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 13 26.982<br>Al<br>ALUMINIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 14 28.086<br>Si<br>SILICON   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 15 30.974<br>P<br>PHOSPHORUS  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 16 32.065<br>S<br>SULPHUR    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 17 35.453<br>Cl<br>CHLORINE   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 18 39.948<br>Ar<br>ARGON      |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 19 39.098<br>K<br>POTASSIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 20 40.078<br>Ca<br>CALCIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 21 44.956<br>Sc<br>SCANDIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 22 47.867<br>Ti<br>TITANIUM      |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 23 50.942<br>V<br>VANADIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 24 51.996<br>Cr<br>CHROMIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 25 54.938<br>Mn<br>MANGANESE |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 26 55.845<br>Fe<br>IRON       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 27 58.933<br>Co<br>COBALT     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 28 58.693<br>Ni<br>NICKEL     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 29 63.546<br>Cu<br>COPPER     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 30 65.39<br>Zn<br>ZINC       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 31 69.723<br>Ga<br>GALLIUM      |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 32 72.64<br>Ge<br>GERMANIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 33 74.922<br>As<br>ARSENIC    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 34 78.96<br>Se<br>SELENIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 35 79.904<br>Br<br>BROMINE |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 36 83.80<br>Kr<br>KRYPTON |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 37 85.468<br>Rb<br>RUBIDIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 38 87.62<br>Sr<br>STRONTIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 39 88.906<br>Y<br>YTTRIUM       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 40 91.224<br>Zr<br>ZIRCONIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 41 92.906<br>Nb<br>NIOBIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 42 95.94<br>Mo<br>MOLYBDENUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 43 (98)<br>Tc<br>TECHNETIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 44 101.07<br>Ru<br>RUTHENIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 45 102.91<br>Rh<br>RHODIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 46 106.42<br>Pd<br>PALLADIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 47 107.87<br>Ag<br>SILVER     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 48 112.41<br>Cd<br>CADMIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 49 114.82<br>In<br>INDIUM       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 50 118.7<br>Sn<br>TIN        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 51 121.76<br>Sb<br>ANTIMONY   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 52 127.60<br>Te<br>TELLURIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 53 126.90<br>I<br>IODINE   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 54 131.29<br>Xe<br>XENON  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 55 132.91<br>Cs<br>CAESIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 56 137.33<br>Ba<br>BARIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 57-71<br>La-Lu<br>Lanthanide    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 72 178.49<br>Hf<br>HAFNIUM       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 73 180.95<br>Ta<br>TANTALUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 74 183.84<br>W<br>TUNGSTEN    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 75 186.21<br>Re<br>RHENIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 76 190.23<br>Os<br>OSMIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 77 192.22<br>Ir<br>IRIDIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 78 195.08<br>Pt<br>PLATINUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 79 196.97<br>Au<br>GOLD       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 80 200.59<br>Hg<br>MERCURY   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 81 204.38<br>Tl<br>THALLIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 82 207.2<br>Pb<br>LEAD       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 83 208.98<br>Bi<br>BISMUTH    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 84 (209)<br>Po<br>POLONIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 85 (210)<br>At<br>ASTATINE |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 86 (222)<br>Rn<br>RADON   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 87 (223)<br>Fr<br>FRANCIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 88 (226)<br>Ra<br>RADIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 89-103<br>Ac-Lr<br>Actinide     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 104 (261)<br>Rf<br>RUTHERFORDIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 105 (262)<br>Db<br>DUBNIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 106 (266)<br>Sg<br>SEABORGIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 107 (264)<br>Bh<br>BOHRIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 108 (277)<br>Hs<br>HASSIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 109 (268)<br>Mt<br>MEITNERIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 110 (281)<br>Uun<br>UNUNNIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 111 (272)<br>Uuh<br>UNUNUNIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 112 (285)<br>Uub<br>UNBIBIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 114 (289)<br>Uuq<br>UNUNQUADIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| LANTHANIDE                   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 57 138.91<br>La<br>LANTHANUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 58 140.12<br>Ce<br>CERIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 59 140.91<br>Pr<br>PRASEODYMIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 60 144.24<br>Nd<br>NEODYMIUM     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 61 (145)<br>Pm<br>PROMETHIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 62 150.36<br>Sm<br>SAMARIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 63 151.96<br>Eu<br>EUROPIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 64 157.25<br>Gd<br>GADOLINIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 65 158.93<br>Tb<br>TERBIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 66 162.50<br>Dy<br>DYSPROSIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 67 164.93<br>Ho<br>HOLMIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 68 167.26<br>Er<br>ERBIUM    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 69 168.93<br>Tm<br>THULIUM      |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 70 173.04<br>Yb<br>YTTERBIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 71 174.97<br>Lu<br>LUTETIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ACTINIDE                     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 89 (227)<br>Ac<br>ACTINIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 90 232.04<br>Th<br>THORIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 91 231.04<br>Pa<br>PROTACTINIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 92 238.03<br>U<br>URANIUM        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 93 (237)<br>Np<br>NEPTUNIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 94 (244)<br>Pu<br>PLUTONIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 95 (243)<br>Am<br>AMERICIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 96 (247)<br>Cm<br>CURIUM      |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 97 (247)<br>Bk<br>BERKELIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 98 (251)<br>Cf<br>CALIFORNIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 99 (252)<br>Es<br>EINSTEINIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 100 (257)<br>Fm<br>FERMIUM   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 101 (258)<br>Md<br>MENDELEVIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 102 (259)<br>No<br>NOBELIUM  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 103 (262)<br>Lr<br>LAWRENCIUM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                            |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



# Review of some metallic fluxes

- Al**
- $T_{\text{melt}} = 660\text{ }^{\circ}\text{C}$
  - attacks silica
  - spin off Al in silica tubes or use NaOH

e.g.  $\text{RB}_4$ ,  $\text{YbAlB}_4$ ,  $\text{RB}_6$ ,  $\text{RBe}_{13}$ ,  $\text{RAl}_3$ ,  $\text{TiB}_2$ ,  $\text{CeSi}_{2-x}$

|                                       |  |                                       |                                       |                                       |                                       |  |                                     |                                      |                                       |                                     |                                      |                                       |                                       |                                      |                                      |                                      |  |  |                                       |                                     |  |                                      |   |                                       |  |   |  |   |  |   |                                 |                                       |  |                                    |                                    |  |
|---------------------------------------|--|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|--|-------------------------------------|--------------------------------------|---------------------------------------|-------------------------------------|--------------------------------------|---------------------------------------|---------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--|--|---------------------------------------|-------------------------------------|--|--------------------------------------|---|---------------------------------------|--|---|--|---|--|---|---------------------------------|---------------------------------------|--|------------------------------------|------------------------------------|--|
| 1<br>1.0079<br><b>H</b><br>HYDROGEN   |  |                                       |                                       |                                       |                                       |  |                                     |                                      |                                       |                                     |                                      |                                       |                                       |                                      |                                      |                                      | 18<br>VIIA<br>2<br>4.0026<br><b>He</b><br>HELIUM |  |                                       |                                     |  |                                      |   |                                       |  |   |  |   |  |   |                                 |                                       |  |                                    |                                    |  |
| 3<br>6.941<br><b>Li</b><br>LITHIUM    | 4<br>9.0122<br><b>Be</b><br>BERYLLIUM  |                                       |                                       |                                       |                                       |  |                                     |                                      |                                       |                                     |                                      |                                       |                                       |                                      |                                      |                                      |  | 10<br>VIIIA<br>20.180<br><b>Ne</b><br>NEON         |                                       |                                     |  |                                      |   |                                       |  |   |  |   |  |   |                                 |                                       |  |                                    |                                    |  |
| 11<br>22.990<br><b>Na</b><br>SODIUM   | 12<br>24.305<br><b>Mg</b><br>MAGNESIUM | 13<br>10.811<br><b>B</b><br>BORON     | 14<br>12.011<br><b>C</b><br>CARBON    | 15<br>14.007<br><b>N</b><br>NITROGEN  | 16<br>15.999<br><b>O</b><br>OXYGEN    | 17<br>18.998<br><b>F</b><br>FLUORINE   | 18<br>20.180<br><b>Ne</b><br>NEON   |                                      |                                       |                                     |                                      |                                       |                                       |                                      |                                      |                                      |  | 18<br>VIIIA<br>36<br>83.80<br><b>Kr</b><br>KRYPTON |                                       |                                     |  |                                      |   |                                       |  |   |  |   |  |   |                                 |                                       |  |                                    |                                    |  |
| 19<br>39.098<br><b>K</b><br>POTASSIUM | 20<br>40.078<br><b>Ca</b><br>CALCIUM   | 21<br>44.956<br><b>Sc</b><br>SCANDIUM | 22<br>47.867<br><b>Ti</b><br>TITANIUM | 23<br>50.942<br><b>V</b><br>VANADIUM  | 24<br>51.996<br><b>Cr</b><br>CHROMIUM | 25<br>54.938<br><b>Mn</b><br>MANGANESE | 26<br>55.845<br><b>Fe</b><br>IRON   | 27<br>58.933<br><b>Co</b><br>COBALT  | 28<br>58.693<br><b>Ni</b><br>NICKEL   | 29<br>63.546<br><b>Cu</b><br>COPPER | 30<br>65.39<br><b>Zn</b><br>ZINC     | 31<br>69.723<br><b>Ga</b><br>GALLIUM  | 32<br>72.64<br><b>Ge</b><br>GERMANIUM | 33<br>74.922<br><b>As</b><br>ARSENIC | 34<br>78.96<br><b>Se</b><br>SELENIUM | 35<br>79.904<br><b>Br</b><br>BROMINE | 36<br>83.80<br><b>Kr</b><br>KRYPTON              | 37<br>85.468<br><b>Rb</b><br>RUBIDIUM              | 38<br>87.62<br><b>Sr</b><br>STRONTIUM | 39<br>88.906<br><b>Y</b><br>YTTRIUM | 40<br>91.224<br><b>Zr</b><br>ZIRCONIUM     | 41<br>92.906<br><b>Nb</b><br>NIOBIUM | 42<br>95.94<br><b>Mo</b><br>MOLYBDENUM  | 43<br>(98)<br><b>Tc</b><br>TECHNETIUM | 44<br>101.07<br><b>Ru</b><br>RUTHENIUM | 45<br>102.91<br><b>Rh</b><br>RHODIUM    | 46<br>106.42<br><b>Pd</b><br>PALLADIUM | 47<br>107.87<br><b>Ag</b><br>SILVER     | 48<br>112.41<br><b>Cd</b><br>CADMIUM   | 49<br>114.82<br><b>In</b><br>INDIUM       | 50<br>118.7<br><b>Sn</b><br>TIN | 51<br>121.76<br><b>Sb</b><br>ANTIMONY | 52<br>127.60<br><b>Te</b><br>TELLURIUM | 53<br>126.90<br><b>I</b><br>IODINE | 54<br>131.29<br><b>Xe</b><br>XENON |  |
| 55<br>132.91<br><b>Cs</b><br>CAESIUM  | 56<br>137.33<br><b>Ba</b><br>BARIUM    | 57-71<br><b>La-Lu</b><br>Lanthanide   | 72<br>178.49<br><b>Hf</b><br>HAFNIUM  | 73<br>180.95<br><b>Ta</b><br>TANTALUM | 74<br>183.84<br><b>W</b><br>TUNGSTEN  | 75<br>186.21<br><b>Re</b><br>RHENIUM   | 76<br>190.23<br><b>Os</b><br>OSMIUM | 77<br>192.22<br><b>Ir</b><br>IRIDIUM | 78<br>195.08<br><b>Pt</b><br>PLATINUM | 79<br>196.97<br><b>Au</b><br>GOLD   | 80<br>200.59<br><b>Hg</b><br>MERCURY | 81<br>204.38<br><b>Tl</b><br>THALLIUM | 82<br>207.2<br><b>Pb</b><br>LEAD      | 83<br>208.98<br><b>Bi</b><br>BISMUTH | 84<br>(209)<br><b>Po</b><br>POLONIUM | 85<br>(210)<br><b>At</b><br>ASTATINE | 86<br>(222)<br><b>Rn</b><br>RADON                | 87<br>(223)<br><b>Fr</b><br>FRANCIUM               | 88<br>(226)<br><b>Ra</b><br>RADIUM    | 89-103<br><b>Ac-Lr</b><br>Actinide  | 104<br>(261)<br><b>Rf</b><br>RUTHERFORDIUM | 105<br>(262)<br><b>Db</b><br>DUBNIUM | 106<br>(266)<br><b>Sg</b><br>SEABORGIUM | 107<br>(264)<br><b>Bh</b><br>BOHRNIUM | 108<br>(277)<br><b>Hs</b><br>HASSIUM   | 109<br>(268)<br><b>Mt</b><br>MEITNERIUM | 110<br>(281)<br><b>Uun</b><br>UNUNNIUM | 111<br>(272)<br><b>Uuh</b><br>UNUNUNIUM | 112<br>(285)<br><b>Uub</b><br>UNBIBIUM | 114<br>(289)<br><b>Uuq</b><br>UNUNQUADIUM |                                 |                                       |  |                                    |                                    |  |

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|  |                                     |   |  |  |                                       |                                       |   |                                      |   |                                      |                                     |                                      |  |                                       |
|--|-------------------------------------|---|--|--|---------------------------------------|---------------------------------------|---|--------------------------------------|---|--------------------------------------|-------------------------------------|--------------------------------------|--|---------------------------------------|
| 57<br>138.91<br><b>La</b><br>LANTHANUM | 58<br>140.12<br><b>Ce</b><br>CERIUM | 59<br>140.91<br><b>Pr</b><br>PRASEODYMIUM | 60<br>144.24<br><b>Nd</b><br>NEODYMIUM | 61<br>(145)<br><b>Pm</b><br>PROMETHIUM | 62<br>150.36<br><b>Sm</b><br>SAMARIUM | 63<br>151.96<br><b>Eu</b><br>EUROPIUM | 64<br>157.25<br><b>Gd</b><br>GADOLINIUM | 65<br>158.93<br><b>Tb</b><br>TERBIUM | 66<br>162.50<br><b>Dy</b><br>DYSPROSIUM | 67<br>164.93<br><b>Ho</b><br>HOLMIUM | 68<br>167.26<br><b>Er</b><br>ERBIUM | 69<br>168.93<br><b>Tm</b><br>THULIUM | 70<br>173.04<br><b>Yb</b><br>YTTERBIUM | 71<br>174.97<br><b>Lu</b><br>LUTETIUM |
|--|-------------------------------------|---|--|--|---------------------------------------|---------------------------------------|---|--------------------------------------|---|--------------------------------------|-------------------------------------|--------------------------------------|--|---------------------------------------|

|                                      |                                      |   |                                     |                                       |                                       |                                       |                                    |                                       |   |   |                                      |  |                                       |   |
|--------------------------------------|--------------------------------------|---|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|---------------------------------------|---|---|--------------------------------------|--|---------------------------------------|---|
| 89<br>(227)<br><b>Ac</b><br>ACTINIUM | 90<br>232.04<br><b>Th</b><br>THORIUM | 91<br>231.04<br><b>Pa</b><br>PROTACTINIUM | 92<br>238.03<br><b>U</b><br>URANIUM | 93<br>(237)<br><b>Np</b><br>NEPTUNIUM | 94<br>(244)<br><b>Pu</b><br>PLUTONIUM | 95<br>(243)<br><b>Am</b><br>AMERICIUM | 96<br>(247)<br><b>Cm</b><br>CURIUM | 97<br>(247)<br><b>Bk</b><br>BERKELIUM | 98<br>(251)<br><b>Cf</b><br>CALIFORNIUM | 99<br>(252)<br><b>Es</b><br>EINSTEINIUM | 100<br>(257)<br><b>Fm</b><br>FERMIUM | 101<br>(258)<br><b>Md</b><br>MENDELEVIUM | 102<br>(259)<br><b>No</b><br>NOBELIUM | 103<br>(262)<br><b>Lr</b><br>LAWRENCIUM |
|--------------------------------------|--------------------------------------|---|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|---------------------------------------|---|---|--------------------------------------|--|---------------------------------------|---|

# Review of some metallic fluxes

- Ga** •  $T_{\text{melt}} = 30\text{ }^{\circ}\text{C}$
- tends to wet surfaces of grown crystal
  - forms compounds with rare-earths

e.g.  $\text{RSb}$ ,  $\text{R}_2\text{Pt}_4\text{Ga}_8$

|                                       |  |                                       |  |                                       |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |                                     |  |                                      |  |                                     |                                       |                                    |
|---------------------------------------|--|---------------------------------------|--|---------------------------------------|---|--|--|---|--|---|--|---|---------------------------------------|---------------------------------------|--|--------------------------------------|-------------------------------------|--|--------------------------------------|--|-------------------------------------|---------------------------------------|------------------------------------|
| 1<br>1.0079<br><b>H</b><br>HYDROGEN   |  |                                       |  |                                       |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      | 18<br>4.0026<br><b>He</b><br>HELIUM |  |                                      |  |                                     |                                       |                                    |
| 3<br>6.941<br><b>Li</b><br>LITHIUM    | 4<br>9.0122<br><b>Be</b><br>BERYLLIUM  |                                       |  |                                       |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |                                     | 5<br>10.811<br><b>B</b><br>BORON       | 6<br>12.011<br><b>C</b><br>CARBON    | 7<br>14.007<br><b>N</b><br>NITROGEN    | 8<br>15.999<br><b>O</b><br>OXYGEN   | 9<br>18.998<br><b>F</b><br>FLUORINE   | 10<br>20.180<br><b>Ne</b><br>NEON  |
| 11<br>22.990<br><b>Na</b><br>SODIUM   | 12<br>24.305<br><b>Mg</b><br>MAGNESIUM |                                       |  |                                       |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |                                     | 13<br>26.982<br><b>Al</b><br>ALUMINIUM | 14<br>28.086<br><b>Si</b><br>SILICON | 15<br>30.974<br><b>P</b><br>PHOSPHORUS | 16<br>32.065<br><b>S</b><br>SULPHUR | 17<br>35.453<br><b>Cl</b><br>CHLORINE | 18<br>39.948<br><b>Ar</b><br>ARGON |
| 19<br>39.098<br><b>K</b><br>POTASSIUM | 20<br>40.078<br><b>Ca</b><br>CALCIUM   | 21<br>44.956<br><b>Sc</b><br>SCANDIUM | 22<br>47.867<br><b>Ti</b><br>TITANIUM      | 23<br>50.942<br><b>V</b><br>VANADIUM  | 24<br>51.996<br><b>Cr</b><br>CHROMIUM   | 25<br>54.938<br><b>Mn</b><br>MANGANESE | 26<br>55.845<br><b>Fe</b><br>IRON      | 27<br>58.933<br><b>Co</b><br>COBALT     | 28<br>58.693<br><b>Ni</b><br>NICKEL    | 29<br>63.546<br><b>Cu</b><br>COPPER     | 30<br>65.39<br><b>Zn</b><br>ZINC       | 31<br>69.723<br><b>Ga</b><br>GALLIUM      | 32<br>72.64<br><b>Ge</b><br>GERMANIUM | 33<br>74.922<br><b>As</b><br>ARSENIC  | 34<br>78.96<br><b>Se</b><br>SELENIUM   | 35<br>79.904<br><b>Br</b><br>BROMINE | 36<br>83.80<br><b>Kr</b><br>KRYPTON |  |                                      |  |                                     |                                       |                                    |
| 37<br>85.468<br><b>Rb</b><br>RUBIDIUM | 38<br>87.62<br><b>Sr</b><br>STRONTIUM  | 39<br>88.906<br><b>Y</b><br>YTTORIUM  | 40<br>91.224<br><b>Zr</b><br>ZIRCONIUM     | 41<br>92.906<br><b>Nb</b><br>NIOBIUM  | 42<br>95.94<br><b>Mo</b><br>MOLYBDENUM  | 43<br>(98)<br><b>Tc</b><br>TECHNETIUM  | 44<br>101.07<br><b>Ru</b><br>RUTHENIUM | 45<br>102.91<br><b>Rh</b><br>RHODIUM    | 46<br>106.42<br><b>Pd</b><br>PALLADIUM | 47<br>107.87<br><b>Ag</b><br>SILVER     | 48<br>112.41<br><b>Cd</b><br>CADMIUM   | 49<br>114.82<br><b>In</b><br>INDIUM       | 50<br>118.7<br><b>Sn</b><br>TIN       | 51<br>121.76<br><b>Sb</b><br>ANTIMONY | 52<br>127.60<br><b>Te</b><br>TELLURIUM | 53<br>126.90<br><b>I</b><br>IODINE   | 54<br>131.29<br><b>Xe</b><br>XENON  |  |                                      |  |                                     |                                       |                                    |
| 55<br>132.91<br><b>Cs</b><br>CAESIUM  | 56<br>137.33<br><b>Ba</b><br>BARIUM    | 57-71<br><b>La-Lu</b><br>Lanthanide   | 72<br>178.49<br><b>Hf</b><br>HAFNIUM       | 73<br>180.95<br><b>Ta</b><br>TANTALUM | 74<br>183.84<br><b>W</b><br>TUNGSTEN    | 75<br>186.21<br><b>Re</b><br>RHENIUM   | 76<br>190.23<br><b>Os</b><br>OSMIUM    | 77<br>192.22<br><b>Ir</b><br>IRIDIUM    | 78<br>195.08<br><b>Pt</b><br>PLATINUM  | 79<br>196.97<br><b>Au</b><br>GOLD       | 80<br>200.59<br><b>Hg</b><br>MERCURY   | 81<br>204.38<br><b>Tl</b><br>THALLIUM     | 82<br>207.2<br><b>Pb</b><br>LEAD      | 83<br>208.98<br><b>Bi</b><br>BISMUTH  | 84<br>(209)<br><b>Po</b><br>POLONIUM   | 85<br>(210)<br><b>At</b><br>ASTATINE | 86<br>(222)<br><b>Rn</b><br>RADON   |  |                                      |  |                                     |                                       |                                    |
| 87<br>(223)<br><b>Fr</b><br>FRANCIUM  | 88<br>(226)<br><b>Ra</b><br>RADIUM     | 89-103<br><b>Ac-Lr</b><br>Actinide    | 104<br>(261)<br><b>Rf</b><br>RUTHERFORDIUM | 105<br>(262)<br><b>Db</b><br>DUBNIUM  | 106<br>(266)<br><b>Sg</b><br>SEABORGIUM | 107<br>(264)<br><b>Bh</b><br>BOHRNIUM  | 108<br>(277)<br><b>Hs</b><br>HASSIUM   | 109<br>(268)<br><b>Mt</b><br>MEITNERIUM | 110<br>(281)<br><b>Uun</b><br>UNUNNIUM | 111<br>(272)<br><b>Uuu</b><br>UNUNUNIUM | 112<br>(285)<br><b>Uub</b><br>UNBIBIUM | 114<br>(289)<br><b>Uuq</b><br>UNUNQUADIUM |                                       |                                       |  |                                      |                                     |  |                                      |  |                                     |                                       |                                    |

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|  |                                     |   |  |  |                                       |                                       |   |                                      |   |                                      |                                     |                                      |  |                                       |
|--|-------------------------------------|---|--|--|---------------------------------------|---------------------------------------|---|--------------------------------------|---|--------------------------------------|-------------------------------------|--------------------------------------|--|---------------------------------------|
| 57<br>138.91<br><b>La</b><br>LANTHANUM | 58<br>140.12<br><b>Ce</b><br>CERIUM | 59<br>140.91<br><b>Pr</b><br>PRASEODYMIUM | 60<br>144.24<br><b>Nd</b><br>NEODYMIUM | 61<br>(145)<br><b>Pm</b><br>PROMETHIUM | 62<br>150.36<br><b>Sm</b><br>SAMARIUM | 63<br>151.96<br><b>Eu</b><br>EUROPIUM | 64<br>157.25<br><b>Gd</b><br>GADOLINIUM | 65<br>158.93<br><b>Tb</b><br>TERBIUM | 66<br>162.50<br><b>Dy</b><br>DYSPROSIUM | 67<br>164.93<br><b>Ho</b><br>HOLMIUM | 68<br>167.26<br><b>Er</b><br>ERBIUM | 69<br>168.93<br><b>Tm</b><br>THULIUM | 70<br>173.04<br><b>Yb</b><br>YTTERBIUM | 71<br>174.97<br><b>Lu</b><br>LUTETIUM |
|--|-------------------------------------|---|--|--|---------------------------------------|---------------------------------------|---|--------------------------------------|---|--------------------------------------|-------------------------------------|--------------------------------------|--|---------------------------------------|

|                                      |                                      |   |                                     |                                       |                                       |                                       |                                    |                                       |   |   |                                      |  |                                       |   |
|--------------------------------------|--------------------------------------|---|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|---------------------------------------|---|---|--------------------------------------|--|---------------------------------------|---|
| 89<br>(227)<br><b>Ac</b><br>ACTINIUM | 90<br>232.04<br><b>Th</b><br>THORIUM | 91<br>231.04<br><b>Pa</b><br>PROTACTINIUM | 92<br>238.03<br><b>U</b><br>URANIUM | 93<br>(237)<br><b>Np</b><br>NEPTUNIUM | 94<br>(244)<br><b>Pu</b><br>PLUTONIUM | 95<br>(243)<br><b>Am</b><br>AMERICIUM | 96<br>(247)<br><b>Cm</b><br>CURIUM | 97<br>(247)<br><b>Bk</b><br>BERKELIUM | 98<br>(251)<br><b>Cf</b><br>CALIFORNIUM | 99<br>(252)<br><b>Es</b><br>EINSTEINIUM | 100<br>(257)<br><b>Fm</b><br>FERMIUM | 101<br>(258)<br><b>Md</b><br>MENDELEVIUM | 102<br>(259)<br><b>No</b><br>NOBELIUM | 103<br>(262)<br><b>Lr</b><br>LAWRENCIUM |
|--------------------------------------|--------------------------------------|---|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|---------------------------------------|---|---|--------------------------------------|--|---------------------------------------|---|



# Review of some metallic fluxes

- In**
- $T_{\text{melt}} = 157\text{ }^{\circ}\text{C}$
  - Proven to be a good flux for  $\text{ThCr}_2\text{Si}_2$ -types
  - $T_{\text{C}} = 3.4\text{ K}$

e.g.  $\text{CeCu}_2\text{Ge}_2$ ,  $\text{CeNi}_2\text{Ge}_2$ ,  $\text{TyCu}_2\text{Si}_2$

|                                       |  |  |  |  |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |                                     |                                    |  |  |  |  |  |  |  |  |  |  |  |  |
|---------------------------------------|--|--|--|--|---|--|--|---|--|---|--|---|---------------------------------------|---------------------------------------|--|--------------------------------------|-------------------------------------|------------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|
| 1<br>1.0079<br><b>H</b><br>HYDROGEN   |  |  |  |  |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      | 18<br>4.0026<br><b>He</b><br>HELIUM |                                    |  |  |  |  |  |  |  |  |  |  |  |  |
| 3<br>6.941<br><b>Li</b><br>LITHIUM    | 4<br>9.0122<br><b>Be</b><br>BERYLLIUM  |  |  |  |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |                                     | 10<br>20.180<br><b>Ne</b><br>NEON  |  |  |  |  |  |  |  |  |  |  |  |  |
| 11<br>22.990<br><b>Na</b><br>SODIUM   | 12<br>24.305<br><b>Mg</b><br>MAGNESIUM | 13<br>26.982<br><b>Al</b><br>ALUMINIUM | 14<br>28.086<br><b>Si</b><br>SILICON       | 15<br>30.974<br><b>P</b><br>PHOSPHORUS | 16<br>32.065<br><b>S</b><br>SULPHUR     | 17<br>35.453<br><b>Cl</b><br>CHLORINE  | 18<br>39.948<br><b>Ar</b><br>ARGON     |   |  |   |  |   |                                       |                                       |  |                                      |                                     | 18<br>39.948<br><b>Ar</b><br>ARGON |  |  |  |  |  |  |  |  |  |  |  |  |
| 19<br>39.098<br><b>K</b><br>POTASSIUM | 20<br>40.078<br><b>Ca</b><br>CALCIUM   | 21<br>44.956<br><b>Sc</b><br>SCANDIUM  | 22<br>47.867<br><b>Ti</b><br>TITANIUM      | 23<br>50.942<br><b>V</b><br>VANADIUM   | 24<br>51.996<br><b>Cr</b><br>CHROMIUM   | 25<br>54.938<br><b>Mn</b><br>MANGANESE | 26<br>55.845<br><b>Fe</b><br>IRON      | 27<br>58.933<br><b>Co</b><br>COBALT     | 28<br>58.693<br><b>Ni</b><br>NICKEL    | 29<br>63.546<br><b>Cu</b><br>COPPER     | 30<br>65.39<br><b>Zn</b><br>ZINC       | 31<br>69.723<br><b>Ga</b><br>GALLIUM      | 32<br>72.64<br><b>Ge</b><br>GERMANIUM | 33<br>74.922<br><b>As</b><br>ARSENIC  | 34<br>78.96<br><b>Se</b><br>SELENIUM   | 35<br>79.904<br><b>Br</b><br>BROMINE | 36<br>83.80<br><b>Kr</b><br>KRYPTON |                                    |  |  |  |  |  |  |  |  |  |  |  | 18<br>83.80<br><b>Kr</b><br>KRYPTON      |
| 37<br>85.468<br><b>Rb</b><br>RUBIDIUM | 38<br>87.62<br><b>Sr</b><br>STRONTIUM  | 39<br>88.906<br><b>Y</b><br>YTTORIUM   | 40<br>91.224<br><b>Zr</b><br>ZIRCONIUM     | 41<br>92.906<br><b>Nb</b><br>NIOBIUM   | 42<br>95.94<br><b>Mo</b><br>MOLYBDENUM  | 43<br>(98)<br><b>Tc</b><br>TECHNETIUM  | 44<br>101.07<br><b>Ru</b><br>RUTHENIUM | 45<br>102.91<br><b>Rh</b><br>RHODIUM    | 46<br>106.42<br><b>Pd</b><br>PALLADIUM | 47<br>107.87<br><b>Ag</b><br>SILVER     | 48<br>112.41<br><b>Cd</b><br>CADMIUM   | 49<br>114.82<br><b>In</b><br>INDIUM       | 50<br>118.7<br><b>Sn</b><br>TIN       | 51<br>121.76<br><b>Sb</b><br>ANTIMONY | 52<br>127.60<br><b>Te</b><br>TELLURIUM | 53<br>126.90<br><b>I</b><br>IODINE   | 54<br>131.29<br><b>Xe</b><br>XENON  |                                    |  |  |  |  |  |  |  |  |  |  |  | 18<br>131.29<br><b>Xe</b><br>XENON       |
| 55<br>132.91<br><b>Cs</b><br>CAESIUM  | 56<br>137.33<br><b>Ba</b><br>BARIUM    | 57-71<br><b>La-Lu</b><br>Lanthanide    | 72<br>178.49<br><b>Hf</b><br>HAFNIUM       | 73<br>180.95<br><b>Ta</b><br>TANTALUM  | 74<br>183.84<br><b>W</b><br>TUNGSTEN    | 75<br>186.21<br><b>Re</b><br>RHENIUM   | 76<br>190.23<br><b>Os</b><br>OSMIUM    | 77<br>192.22<br><b>Ir</b><br>IRIDIUM    | 78<br>195.08<br><b>Pt</b><br>PLATINUM  | 79<br>196.97<br><b>Au</b><br>GOLD       | 80<br>200.59<br><b>Hg</b><br>MERCURY   | 81<br>204.38<br><b>Tl</b><br>THALLIUM     | 82<br>207.2<br><b>Pb</b><br>LEAD      | 83<br>208.98<br><b>Bi</b><br>BISMUTH  | 84<br>(209)<br><b>Po</b><br>POLONIUM   | 85<br>(210)<br><b>At</b><br>ASTATINE | 86<br>(222)<br><b>Rn</b><br>RADON   |                                    |  |  |  |  |  |  |  |  |  |  |  | 18<br>(222)<br><b>Rn</b><br>RADON        |
| 87<br>(223)<br><b>Fr</b><br>FRANCIUM  | 88<br>(226)<br><b>Ra</b><br>RADIUM     | 89-103<br><b>Ac-Lr</b><br>Actinide     | 104<br>(261)<br><b>Rf</b><br>RUTHERFORDIUM | 105<br>(262)<br><b>Db</b><br>DUBNIUM   | 106<br>(266)<br><b>Sg</b><br>SEABORGIUM | 107<br>(264)<br><b>Bh</b><br>BOHRIUM   | 108<br>(277)<br><b>Hs</b><br>HASSIUM   | 109<br>(268)<br><b>Mt</b><br>MEITNERIUM | 110<br>(281)<br><b>Uun</b><br>UNUNNIUM | 111<br>(272)<br><b>Uuh</b><br>UNUNUNIUM | 112<br>(285)<br><b>Uub</b><br>UNBIBIUM | 114<br>(289)<br><b>Uuq</b><br>UNUNQUADIUM |                                       |                                       |  |                                      |                                     |                                    |  |  |  |  |  |  |  |  |  |  |  | 18<br>(289)<br><b>Uuq</b><br>UNUNQUADIUM |

LANTHANIDE

57 138.91  
**La**  
LANTHANUM

58 140.12  
**Ce**  
CERIUM

59 140.91  
**Pr**  
PRASEODYMIUM

60 144.24  
**Nd**  
NEODYMIUM

61 (145)  
**Pm**  
PROMETHIUM

62 150.36  
**Sm**  
SAMARIUM

63 151.96  
**Eu**  
EUROPIUM

64 157.25  
**Gd**  
GADOLINIUM

65 158.93  
**Tb**  
TERBIUM

66 162.50  
**Dy**  
DYSPROSIUM

67 164.93  
**Ho**  
HOLMIUM

68 167.26  
**Er**  
ERBIUM

69 168.93  
**Tm**  
THULIUM

70 173.04  
**Yb**  
YTTERBIUM

71 174.97  
**Lu**  
LUTETIUM

ACTINIDE

89 (227)  
**Ac**  
ACTINIUM

90 232.04  
**Th**  
THORIUM

91 231.04  
**Pa**  
PROTACTINIUM

92 238.03  
**U**  
URANIUM

93 (237)  
**Np**  
NEPTUNIUM

94 (244)  
**Pu**  
PLUTONIUM

95 (243)  
**Am**  
AMERICIUM

96 (247)  
**Cm**  
CURIUM

97 (247)  
**Bk**  
BERKELIUM

98 (251)  
**Cf**  
CALIFORNIUM

99 (252)  
**Es**  
EINSTEINIUM

100 (257)  
**Fm**  
FERMIUM

101 (258)  
**Md**  
MENDELEVIUM

102 (259)  
**No**  
NOBELIUM

103 (262)  
**Lr**  
LAWRENCIUM

# Review of some metallic fluxes

- Sn; Pb** •  $T_{\text{melt}} = 232\text{ }^{\circ}\text{C}; 327\text{ }^{\circ}\text{C}$   
 • form  $\text{RPb}_3$ ,  $\text{RSn}_3$  phases  
 •  $T_{\text{C}} = 3.7\text{ K}; 7.2\text{ K}$

e.g.  $\text{YbCu}_2\text{Si}_2$ ,  $\text{TiNiSn}$ ,  $\text{MnSnNi}$ ,  $\text{RSb}$ ;  $\text{RBiPt}$ ,  $\text{RPbPt}$

|                                       |  |                                       |  |                                       |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |                                     |  |                                      |  |                                     |                                       |                                    |
|---------------------------------------|--|---------------------------------------|--|---------------------------------------|---|--|--|---|--|---|--|---|---------------------------------------|---------------------------------------|--|--------------------------------------|-------------------------------------|--|--------------------------------------|--|-------------------------------------|---------------------------------------|------------------------------------|
| 1<br>1.0079<br><b>H</b><br>HYDROGEN   |  |                                       |  |                                       |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      | 18<br>4.0026<br><b>He</b><br>HELIUM |  |                                      |  |                                     |                                       |                                    |
| 3<br>6.941<br><b>Li</b><br>LITHIUM    | 4<br>9.0122<br><b>Be</b><br>BERYLLIUM  |                                       |  |                                       |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |                                     | 5<br>10.811<br><b>B</b><br>BORON       | 6<br>12.011<br><b>C</b><br>CARBON    | 7<br>14.007<br><b>N</b><br>NITROGEN    | 8<br>15.999<br><b>O</b><br>OXYGEN   | 9<br>18.998<br><b>F</b><br>FLUORINE   | 10<br>20.180<br><b>Ne</b><br>NEON  |
| 11<br>22.990<br><b>Na</b><br>SODIUM   | 12<br>24.305<br><b>Mg</b><br>MAGNESIUM |                                       |  |                                       |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |                                     | 13<br>26.982<br><b>Al</b><br>ALUMINIUM | 14<br>28.086<br><b>Si</b><br>SILICON | 15<br>30.974<br><b>P</b><br>PHOSPHORUS | 16<br>32.065<br><b>S</b><br>SULPHUR | 17<br>35.453<br><b>Cl</b><br>CHLORINE | 18<br>39.948<br><b>Ar</b><br>ARGON |
| 19<br>39.098<br><b>K</b><br>POTASSIUM | 20<br>40.078<br><b>Ca</b><br>CALCIUM   | 21<br>44.956<br><b>Sc</b><br>SCANDIUM | 22<br>47.867<br><b>Ti</b><br>TITANIUM      | 23<br>50.942<br><b>V</b><br>VANADIUM  | 24<br>51.996<br><b>Cr</b><br>CHROMIUM   | 25<br>54.938<br><b>Mn</b><br>MANGANESE | 26<br>55.845<br><b>Fe</b><br>IRON      | 27<br>58.933<br><b>Co</b><br>COBALT     | 28<br>58.693<br><b>Ni</b><br>NICKEL    | 29<br>63.546<br><b>Cu</b><br>COPPER     | 30<br>65.39<br><b>Zn</b><br>ZINC       | 31<br>69.723<br><b>Ga</b><br>GALLIUM      | 32<br>72.64<br><b>Ge</b><br>GERMANIUM | 33<br>74.922<br><b>As</b><br>ARSENIC  | 34<br>78.96<br><b>Se</b><br>SELENIUM   | 35<br>79.904<br><b>Br</b><br>BROMINE | 36<br>83.80<br><b>Kr</b><br>KRYPTON |  |                                      |  |                                     |                                       |                                    |
| 37<br>85.468<br><b>Rb</b><br>RUBIDIUM | 38<br>87.62<br><b>Sr</b><br>STRONTIUM  | 39<br>88.906<br><b>Y</b><br>YTTRIUM   | 40<br>91.224<br><b>Zr</b><br>ZIRCONIUM     | 41<br>92.906<br><b>Nb</b><br>NIOBIUM  | 42<br>95.94<br><b>Mo</b><br>MOLYBDENUM  | 43<br>(98)<br><b>Tc</b><br>TECHNETIUM  | 44<br>101.07<br><b>Ru</b><br>RUTHENIUM | 45<br>102.91<br><b>Rh</b><br>RHODIUM    | 46<br>106.42<br><b>Pd</b><br>PALLADIUM | 47<br>107.87<br><b>Ag</b><br>SILVER     | 48<br>112.41<br><b>Cd</b><br>CADMIUM   | 49<br>114.82<br><b>In</b><br>INDIUM       | 50<br>118.7<br><b>Sn</b><br>TIN       | 51<br>121.76<br><b>Sb</b><br>ANTIMONY | 52<br>127.60<br><b>Te</b><br>TELLURIUM | 53<br>126.90<br><b>I</b><br>IODINE   | 54<br>131.29<br><b>Xe</b><br>XENON  |  |                                      |  |                                     |                                       |                                    |
| 55<br>132.91<br><b>Cs</b><br>CAESIUM  | 56<br>137.33<br><b>Ba</b><br>BARIUM    | 57-71<br><b>La-Lu</b><br>Lanthanide   | 72<br>178.49<br><b>Hf</b><br>HAFNIUM       | 73<br>180.95<br><b>Ta</b><br>TANTALUM | 74<br>183.84<br><b>W</b><br>TUNGSTEN    | 75<br>186.21<br><b>Re</b><br>RHENIUM   | 76<br>190.23<br><b>Os</b><br>OSMIUM    | 77<br>192.22<br><b>Ir</b><br>IRIDIUM    | 78<br>195.08<br><b>Pt</b><br>PLATINUM  | 79<br>196.97<br><b>Au</b><br>GOLD       | 80<br>200.59<br><b>Hg</b><br>MERCURY   | 81<br>204.38<br><b>Tl</b><br>THALLIUM     | 82<br>207.2<br><b>Pb</b><br>LEAD      | 83<br>208.98<br><b>Bi</b><br>BISMUTH  | 84<br>(209)<br><b>Po</b><br>POLONIUM   | 85<br>(210)<br><b>At</b><br>ASTATINE | 86<br>(222)<br><b>Rn</b><br>RADON   |  |                                      |  |                                     |                                       |                                    |
| 87<br>(223)<br><b>Fr</b><br>FRANCIUM  | 88<br>(226)<br><b>Ra</b><br>RADIUM     | 89-103<br><b>Ac-Lr</b><br>Actinide    | 104<br>(261)<br><b>Rf</b><br>RUTHERFORDIUM | 105<br>(262)<br><b>Db</b><br>DUBNIUM  | 106<br>(266)<br><b>Sg</b><br>SEABORGIUM | 107<br>(264)<br><b>Bh</b><br>BOHRNIUM  | 108<br>(277)<br><b>Hs</b><br>HASSIUM   | 109<br>(268)<br><b>Mt</b><br>MEITNERIUM | 110<br>(281)<br><b>Uun</b><br>UNUNNIUM | 111<br>(272)<br><b>Uuu</b><br>UNUNUNIUM | 112<br>(285)<br><b>Uub</b><br>UNBIBIUM | 114<br>(289)<br><b>Uuq</b><br>UNUNQUADIUM |                                       |                                       |  |                                      |                                     |  |                                      |  |                                     |                                       |                                    |

LANTHANIDE

|  |                                     |   |  |  |                                       |                                       |   |                                      |   |                                      |                                     |                                      |  |                                       |
|--|-------------------------------------|---|--|--|---------------------------------------|---------------------------------------|---|--------------------------------------|---|--------------------------------------|-------------------------------------|--------------------------------------|--|---------------------------------------|
| 57<br>138.91<br><b>La</b><br>LANTHANUM | 58<br>140.12<br><b>Ce</b><br>CERIUM | 59<br>140.91<br><b>Pr</b><br>PRASEODYMIUM | 60<br>144.24<br><b>Nd</b><br>NEODYMIUM | 61<br>(145)<br><b>Pm</b><br>PROMETHIUM | 62<br>150.36<br><b>Sm</b><br>SAMARIUM | 63<br>151.96<br><b>Eu</b><br>EUROPIUM | 64<br>157.25<br><b>Gd</b><br>GADOLINIUM | 65<br>158.93<br><b>Tb</b><br>TERBIUM | 66<br>162.50<br><b>Dy</b><br>DYSPROSIUM | 67<br>164.93<br><b>Ho</b><br>HOLMIUM | 68<br>167.26<br><b>Er</b><br>ERBIUM | 69<br>168.93<br><b>Tm</b><br>THULIUM | 70<br>173.04<br><b>Yb</b><br>YTTERBIUM | 71<br>174.97<br><b>Lu</b><br>LUTETIUM |
|--|-------------------------------------|---|--|--|---------------------------------------|---------------------------------------|---|--------------------------------------|---|--------------------------------------|-------------------------------------|--------------------------------------|--|---------------------------------------|

ACTINIDE

|                                      |                                      |   |                                     |                                       |                                       |                                       |                                    |                                       |   |   |                                      |   |                                       |   |
|--------------------------------------|--------------------------------------|---|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|---------------------------------------|---|---|--------------------------------------|---|---------------------------------------|---|
| 89<br>(227)<br><b>Ac</b><br>ACTINIUM | 90<br>232.04<br><b>Th</b><br>THORIUM | 91<br>231.04<br><b>Pa</b><br>PROTACTINIUM | 92<br>238.03<br><b>U</b><br>URANIUM | 93<br>(237)<br><b>Np</b><br>NEPTUNIUM | 94<br>(244)<br><b>Pu</b><br>PLUTONIUM | 95<br>(243)<br><b>Am</b><br>AMERICIUM | 96<br>(247)<br><b>Cm</b><br>CURIUM | 97<br>(247)<br><b>Bk</b><br>BERKELIUM | 98<br>(251)<br><b>Cf</b><br>CALIFORNIUM | 99<br>(252)<br><b>Es</b><br>EINSTEINIUM | 100<br>(257)<br><b>Fm</b><br>FERMIUM | 101<br>(258)<br><b>Md</b><br>MEDELEVIUM | 102<br>(259)<br><b>No</b><br>NOBELIUM | 103<br>(262)<br><b>Lr</b><br>LAWRENCIUM |
|--------------------------------------|--------------------------------------|---|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|---------------------------------------|---|---|--------------------------------------|---|---------------------------------------|---|

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# Review of some metallic fluxes

- Sb**
- $T_{\text{melt}} = 630\text{ }^{\circ}\text{C}$
  - stability of  $R\text{-Sb}$  phases

e.g.  $\text{RSb}_2$ ,  $\text{U}_3\text{Sb}_4\text{Pt}_3$ ,  $\text{PtSb}_2$

|  |  |   |  |  |                                       |  |   |                                       |   |   |                                      |  |  |   |                                      |                                      |                                     |  |                                       |  |  |                                       |   |                                       |  |   |  |   |                                       |   |                                 |                                       |  |                                    |                                    |  |  |  |  |  |
|--|--|---|--|--|---------------------------------------|--|---|---------------------------------------|---|---|--------------------------------------|--|--|---|--------------------------------------|--------------------------------------|-------------------------------------|--|---------------------------------------|--|--|---------------------------------------|---|---------------------------------------|--|---|--|---|---------------------------------------|---|---------------------------------|---------------------------------------|--|------------------------------------|------------------------------------|--|--|--|--|--|
| 1<br>1.0079<br><b>H</b><br>HYDROGEN    |  |   |  |  |                                       |  |   |                                       |   |   |                                      |  |  |   |                                      |                                      | 18<br>4.0026<br><b>He</b><br>HELIUM |  |                                       |  |  |                                       |   |                                       |  |   |  |   |                                       |   |                                 |                                       |  |                                    |                                    |  |  |  |  |  |
| 3<br>6.941<br><b>Li</b><br>LITHIUM     | 4<br>9.0122<br><b>Be</b><br>BERYLLIUM  |   |  |  |                                       |  |   |                                       |   |   |                                      |  |  |   |                                      |                                      |                                     | 5<br>10.811<br><b>B</b><br>BORON       | 6<br>12.011<br><b>C</b><br>CARBON     | 7<br>14.007<br><b>N</b><br>NITROGEN    | 8<br>15.999<br><b>O</b><br>OXYGEN          | 9<br>18.998<br><b>F</b><br>FLUORINE   | 10<br>20.180<br><b>Ne</b><br>NEON       |                                       |  |   |  |   |                                       |   |                                 |                                       |  |                                    |                                    |  |  |  |  |  |
| 11<br>22.990<br><b>Na</b><br>SODIUM    | 12<br>24.305<br><b>Mg</b><br>MAGNESIUM |   |  |  |                                       |  |   |                                       |   |   |                                      |  |  |   |                                      |                                      |                                     | 13<br>26.982<br><b>Al</b><br>ALUMINIUM | 14<br>28.086<br><b>Si</b><br>SILICON  | 15<br>30.974<br><b>P</b><br>PHOSPHORUS | 16<br>32.065<br><b>S</b><br>SULPHUR        | 17<br>35.453<br><b>Cl</b><br>CHLORINE | 18<br>39.948<br><b>Ar</b><br>ARGON      |                                       |  |   |  |   |                                       |   |                                 |                                       |  |                                    |                                    |  |  |  |  |  |
| 19<br>39.098<br><b>K</b><br>POTASSIUM  | 20<br>40.078<br><b>Ca</b><br>CALCIUM   | 21<br>44.956<br><b>Sc</b><br>SCANDIUM     | 22<br>47.867<br><b>Ti</b><br>TITANIUM  | 23<br>50.942<br><b>V</b><br>VANADIUM   | 24<br>51.996<br><b>Cr</b><br>CHROMIUM | 25<br>54.938<br><b>Mn</b><br>MANGANESE | 26<br>55.845<br><b>Fe</b><br>IRON       | 27<br>58.933<br><b>Co</b><br>COBALT   | 28<br>58.693<br><b>Ni</b><br>NICKEL     | 29<br>63.546<br><b>Cu</b><br>COPPER     | 30<br>65.39<br><b>Zn</b><br>ZINC     | 31<br>69.723<br><b>Ga</b><br>GALLIUM     | 32<br>72.64<br><b>Ge</b><br>GERMANIUM  | 33<br>74.922<br><b>As</b><br>ARSENIC    | 34<br>78.96<br><b>Se</b><br>SELENIUM | 35<br>79.904<br><b>Br</b><br>BROMINE | 36<br>83.80<br><b>Kr</b><br>KRYPTON | 37<br>85.468<br><b>Rb</b><br>RUBIDIUM  | 38<br>87.62<br><b>Sr</b><br>STRONTIUM | 39<br>88.906<br><b>Y</b><br>YTTRIUM    | 40<br>91.224<br><b>Zr</b><br>ZIRCONIUM     | 41<br>92.906<br><b>Nb</b><br>NIOBIUM  | 42<br>95.94<br><b>Mo</b><br>MOLYBDENUM  | 43<br>(98)<br><b>Tc</b><br>TECHNETIUM | 44<br>101.07<br><b>Ru</b><br>RUTHENIUM | 45<br>102.91<br><b>Rh</b><br>RHODIUM    | 46<br>106.42<br><b>Pd</b><br>PALLADIUM | 47<br>107.87<br><b>Ag</b><br>SILVER           | 48<br>112.41<br><b>Cd</b><br>CADMIUM  | 49<br>114.82<br><b>In</b><br>INDIUM       | 50<br>118.7<br><b>Sn</b><br>TIN | 51<br>121.76<br><b>Sb</b><br>ANTIMONY | 52<br>127.60<br><b>Te</b><br>TELLURIUM | 53<br>126.90<br><b>I</b><br>IODINE | 54<br>131.29<br><b>Xe</b><br>XENON |  |  |  |  |  |
| 55<br>132.91<br><b>Cs</b><br>CAESIUM   | 56<br>137.33<br><b>Ba</b><br>BARIUM    | 57-71<br><b>La-Lu</b><br>Lanthanide       | 72<br>178.49<br><b>Hf</b><br>HAFNIUM   | 73<br>180.95<br><b>Ta</b><br>TANTALUM  | 74<br>183.84<br><b>W</b><br>TUNGSTEN  | 75<br>186.21<br><b>Re</b><br>RHENIUM   | 76<br>190.23<br><b>Os</b><br>OSMIUM     | 77<br>192.22<br><b>Ir</b><br>IRIDIUM  | 78<br>195.08<br><b>Pt</b><br>PLATINUM   | 79<br>196.97<br><b>Au</b><br>GOLD       | 80<br>200.59<br><b>Hg</b><br>MERCURY | 81<br>204.38<br><b>Tl</b><br>THALLIUM    | 82<br>207.2<br><b>Pb</b><br>LEAD       | 83<br>208.98<br><b>Bi</b><br>BISMUTH    | 84<br>(209)<br><b>Po</b><br>POLONIUM | 85<br>(210)<br><b>At</b><br>ASTATINE | 86<br>(222)<br><b>Rn</b><br>RADON   | 87<br>(223)<br><b>Fr</b><br>FRANCIUM   | 88<br>(226)<br><b>Ra</b><br>RADIUM    | 89-103<br><b>Ac-Lr</b><br>Actinide     | 104<br>(261)<br><b>Rf</b><br>RUTHERFORDIUM | 105<br>(262)<br><b>Db</b><br>DUBNIUM  | 106<br>(266)<br><b>Sg</b><br>SEABORGIUM | 107<br>(264)<br><b>Bh</b><br>BOHRNIUM | 108<br>(277)<br><b>Hs</b><br>HASSIUM   | 109<br>(268)<br><b>Mt</b><br>MEITNERIUM | 110<br>(281)<br><b>Uun</b><br>UNUNNIUM | 111<br>(272)<br><b>Uuu</b><br>UNUNUNIUM       | 112<br>(285)<br><b>Uub</b><br>UNUBIUM | 114<br>(289)<br><b>Uuq</b><br>UNUNQUADIUM |                                 |                                       |  |                                    |                                    |  |  |  |  |  |
| LANTHANIDE                             |  |   |  |  |                                       |  |   |                                       |   |   |                                      |  |  |   |                                      |                                      |                                     |  |                                       |  |  |                                       |   |                                       |  |   |  | Copyright © 1998-2003 EniG. (eni@kf-split.hr) |                                       |   |                                 |                                       |  |                                    |                                    |  |  |  |  |  |
| 57<br>138.91<br><b>La</b><br>LANTHANUM | 58<br>140.12<br><b>Ce</b><br>CERIUM    | 59<br>140.91<br><b>Pr</b><br>PRASEODYMIUM | 60<br>144.24<br><b>Nd</b><br>NEODYMIUM | 61<br>(145)<br><b>Pm</b><br>PROMETHIUM | 62<br>150.36<br><b>Sm</b><br>SAMARIUM | 63<br>151.96<br><b>Eu</b><br>EUROPIUM  | 64<br>157.25<br><b>Gd</b><br>GADOLINIUM | 65<br>158.93<br><b>Tb</b><br>TERBIUM  | 66<br>162.50<br><b>Dy</b><br>DYSPROSIUM | 67<br>164.93<br><b>Ho</b><br>HOLMIUM    | 68<br>167.26<br><b>Er</b><br>ERBIUM  | 69<br>168.93<br><b>Tm</b><br>THULIUM     | 70<br>173.04<br><b>Yb</b><br>YTTERBIUM | 71<br>174.97<br><b>Lu</b><br>LUTETIUM   |                                      |                                      |                                     |  |                                       |  |  |                                       |   |                                       |  |   |  |   |                                       |   |                                 |                                       |  |                                    |                                    |  |  |  |  |  |
| ACTINIDE                               |  |   |  |  |                                       |  |   |                                       |   |   |                                      |  |  |   |                                      |                                      |                                     |  |                                       |  |  |                                       |   |                                       |  |   |  |   |                                       |   |                                 |                                       |  |                                    |                                    |  |  |  |  |  |
| 89<br>(227)<br><b>Ac</b><br>ACTINIUM   | 90<br>232.04<br><b>Th</b><br>THORIUM   | 91<br>231.04<br><b>Pa</b><br>PROTACTINIUM | 92<br>238.03<br><b>U</b><br>URANIUM    | 93<br>(237)<br><b>Np</b><br>NEPTUNIUM  | 94<br>(244)<br><b>Pu</b><br>PLUTONIUM | 95<br>(243)<br><b>Am</b><br>AMERICIUM  | 96<br>(247)<br><b>Cm</b><br>CURIUM      | 97<br>(247)<br><b>Bk</b><br>BERKELIUM | 98<br>(251)<br><b>Cf</b><br>CALIFORNIUM | 99<br>(252)<br><b>Es</b><br>EINSTEINIUM | 100<br>(257)<br><b>Fm</b><br>FERMIUM | 101<br>(258)<br><b>Md</b><br>MENDELEVIUM | 102<br>(259)<br><b>No</b><br>NOBELIUM  | 103<br>(262)<br><b>Lr</b><br>LAWRENCIUM |                                      |                                      |                                     |  |                                       |  |  |                                       |   |                                       |  |   |  |   |                                       |   |                                 |                                       |  |                                    |                                    |  |  |  |  |  |



# Review of some metallic fluxes

**Zn**  $T_{\text{melt}} = 420\text{ }^{\circ}\text{C}$  e.g. InSb, GaSb, InAs, Si, Ge

**Bi**  $T_{\text{melt}} = 272\text{ }^{\circ}\text{C}$  e.g. UPt<sub>3</sub>, PtMnSb, NiMnSb, UAl<sub>3</sub>, GaP, ZnSiP<sub>2</sub>, CdSiP<sub>2</sub>

**Cu**  $T_{\text{melt}} = 1085\text{ }^{\circ}\text{C}$  e.g.  $R\text{Ph}_4\text{B}_4$ ,  $\text{RCu}_2\text{Si}_2$ ,  $\text{V}_3\text{Si}$ ,  $\text{RIr}_2$ ,  $\text{UIr}_3$

|                                       |  |  |  |  |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |  |  |  |  |  |  |   |  |  |  |  |  |  |   |
|---------------------------------------|--|--|--|--|---|--|--|---|--|---|--|---|---------------------------------------|---------------------------------------|--|--------------------------------------|--|--|--|--|--|--|---|--|--|--|--|--|--|---|
| 1<br>1.0079<br><b>H</b><br>HYDROGEN   |  |  |  |  |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      | 18<br>VIIA<br>2<br>4.0026<br><b>He</b><br>HELIUM |  |  |  |  |  |   |  |  |  |  |  |  |   |
| 3<br>6.941<br><b>Li</b><br>LITHIUM    | 4<br>9.0122<br><b>Be</b><br>BERYLLIUM  |  |  |  |   |  |  |   |  |   |  |   |                                       |                                       |  |                                      |  | 10<br>VIIIA<br>20<br>18.998<br><b>Ne</b><br>NEON   |  |  |  |  |   |  |  |  |  |  |  |   |
| 11<br>22.990<br><b>Na</b><br>SODIUM   | 12<br>24.305<br><b>Mg</b><br>MAGNESIUM | 13<br>26.982<br><b>Al</b><br>ALUMINIUM | 14<br>28.086<br><b>Si</b><br>SILICON       | 15<br>30.974<br><b>P</b><br>PHOSPHORUS | 16<br>32.065<br><b>S</b><br>SULPHUR     | 17<br>35.453<br><b>Cl</b><br>CHLORINE  | 18<br>39.948<br><b>Ar</b><br>ARGON     |   |  |   |  |   |                                       |                                       |  |                                      |  | 18<br>VIIIA<br>36<br>83.80<br><b>Kr</b><br>KRYPTON |  |  |  |  |   |  |  |  |  |  |  |   |
| 19<br>39.098<br><b>K</b><br>POTASSIUM | 20<br>40.078<br><b>Ca</b><br>CALCIUM   | 21<br>44.956<br><b>Sc</b><br>SCANDIUM  | 22<br>47.867<br><b>Ti</b><br>TITANIUM      | 23<br>50.942<br><b>V</b><br>VANADIUM   | 24<br>51.996<br><b>Cr</b><br>CHROMIUM   | 25<br>54.938<br><b>Mn</b><br>MANGANESE | 26<br>55.845<br><b>Fe</b><br>IRON      | 27<br>58.933<br><b>Co</b><br>COBALT     | 28<br>58.693<br><b>Ni</b><br>NICKEL    | 29<br>63.546<br><b>Cu</b><br>COPPER     | 30<br>65.39<br><b>Zn</b><br>ZINC       | 31<br>69.723<br><b>Ga</b><br>GALLIUM      | 32<br>72.64<br><b>Ge</b><br>GERMANIUM | 33<br>74.922<br><b>As</b><br>ARSENIC  | 34<br>78.96<br><b>Se</b><br>SELENIUM   | 35<br>79.904<br><b>Br</b><br>BROMINE | 36<br>83.80<br><b>Kr</b><br>KRYPTON              |  |  |  |  |  |   |  |  |  |  |  |  | 18<br>VIIIA<br>54<br>131.29<br><b>Xe</b><br>XENON     |
| 37<br>85.468<br><b>Rb</b><br>RUBIDIUM | 38<br>87.62<br><b>Sr</b><br>STRONTIUM  | 39<br>88.906<br><b>Y</b><br>YTTRIUM    | 40<br>91.224<br><b>Zr</b><br>ZIRCONIUM     | 41<br>92.906<br><b>Nb</b><br>NIOBIUM   | 42<br>95.94<br><b>Mo</b><br>MOLYBDENUM  | 43<br>(98)<br><b>Tc</b><br>TECHNETIUM  | 44<br>101.07<br><b>Ru</b><br>RUTHENIUM | 45<br>102.91<br><b>Rh</b><br>RHODIUM    | 46<br>106.42<br><b>Pd</b><br>PALLADIUM | 47<br>107.87<br><b>Ag</b><br>SILVER     | 48<br>112.41<br><b>Cd</b><br>CADMIUM   | 49<br>114.82<br><b>In</b><br>INDIUM       | 50<br>118.7<br><b>Sn</b><br>TIN       | 51<br>121.76<br><b>Sb</b><br>ANTIMONY | 52<br>127.60<br><b>Te</b><br>TELLURIUM | 53<br>126.90<br><b>I</b><br>IODINE   | 54<br>131.29<br><b>Xe</b><br>XENON               |  |  |  |  |  |   |  |  |  |  |  |  | 18<br>VIIIA<br>86<br>(222)<br><b>Rn</b><br>RADON      |
| 55<br>132.91<br><b>Cs</b><br>CAESIUM  | 56<br>137.33<br><b>Ba</b><br>BARIUM    | 57-71<br>La-Lu<br>Lanthanide           | 72<br>178.49<br><b>Hf</b><br>HAFNIUM       | 73<br>180.95<br><b>Ta</b><br>TANTALUM  | 74<br>183.84<br><b>W</b><br>TUNGSTEN    | 75<br>186.21<br><b>Re</b><br>RHENIUM   | 76<br>190.23<br><b>Os</b><br>OSMIUM    | 77<br>192.22<br><b>Ir</b><br>IRIDIUM    | 78<br>195.08<br><b>Pt</b><br>PLATINUM  | 79<br>196.97<br><b>Au</b><br>GOLD       | 80<br>200.59<br><b>Hg</b><br>MERCURY   | 81<br>204.38<br><b>Tl</b><br>THALLIUM     | 82<br>207.2<br><b>Pb</b><br>LEAD      | 83<br>208.98<br><b>Bi</b><br>BISMUTH  | 84<br>(209)<br><b>Po</b><br>POLONIUM   | 85<br>(210)<br><b>At</b><br>ASTATINE | 86<br>(222)<br><b>Rn</b><br>RADON                |  |  |  |  |  |   |  |  |  |  |  |  | 18<br>VIIIA<br>118<br>(294)<br><b>Og</b><br>Oganesson |
| 87<br>(223)<br><b>Fr</b><br>FRANCIUM  | 88<br>(226)<br><b>Ra</b><br>RADIUM     | 89-103<br>Ac-Lr<br>Actinide            | 104<br>(261)<br><b>Rf</b><br>RUTHERFORDIUM | 105<br>(262)<br><b>Db</b><br>DUBNIUM   | 106<br>(266)<br><b>Sg</b><br>SEABORGIUM | 107<br>(264)<br><b>Bh</b><br>BOHRNIUM  | 108<br>(277)<br><b>Hs</b><br>HASSIUM   | 109<br>(268)<br><b>Mt</b><br>MEITNERIUM | 110<br>(281)<br><b>Uu</b><br>UNUNNIUM  | 111<br>(272)<br><b>Uuh</b><br>UNUNUNIUM | 112<br>(285)<br><b>Uub</b><br>UNBIBIUM | 114<br>(289)<br><b>Uuq</b><br>UNUNQUADIUM |                                       |                                       |  |                                      |  |  |  |  |  |  | 18<br>VIIIA<br>118<br>(294)<br><b>Og</b><br>Oganesson |  |  |  |  |  |  |   |

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|  |                                     |   |  |  |                                       |                                       |   |                                      |   |                                      |                                     |                                      |  |                                       |
|--|-------------------------------------|---|--|--|---------------------------------------|---------------------------------------|---|--------------------------------------|---|--------------------------------------|-------------------------------------|--------------------------------------|--|---------------------------------------|
| 57<br>138.91<br><b>La</b><br>LANTHANUM | 58<br>140.12<br><b>Ce</b><br>CERIUM | 59<br>140.91<br><b>Pr</b><br>PRASEODYMIUM | 60<br>144.24<br><b>Nd</b><br>NEODYMIUM | 61<br>(145)<br><b>Pm</b><br>PROMETHIUM | 62<br>150.36<br><b>Sm</b><br>SAMARIUM | 63<br>151.96<br><b>Eu</b><br>EUROPIUM | 64<br>157.25<br><b>Gd</b><br>GADOLINIUM | 65<br>158.93<br><b>Tb</b><br>TERBIUM | 66<br>162.50<br><b>Dy</b><br>DYSPROSIUM | 67<br>164.93<br><b>Ho</b><br>HOLMIUM | 68<br>167.26<br><b>Er</b><br>ERBIUM | 69<br>168.93<br><b>Tm</b><br>THULIUM | 70<br>173.04<br><b>Yb</b><br>YTTERBIUM | 71<br>174.97<br><b>Lu</b><br>LUTETIUM |
|--|-------------------------------------|---|--|--|---------------------------------------|---------------------------------------|---|--------------------------------------|---|--------------------------------------|-------------------------------------|--------------------------------------|--|---------------------------------------|

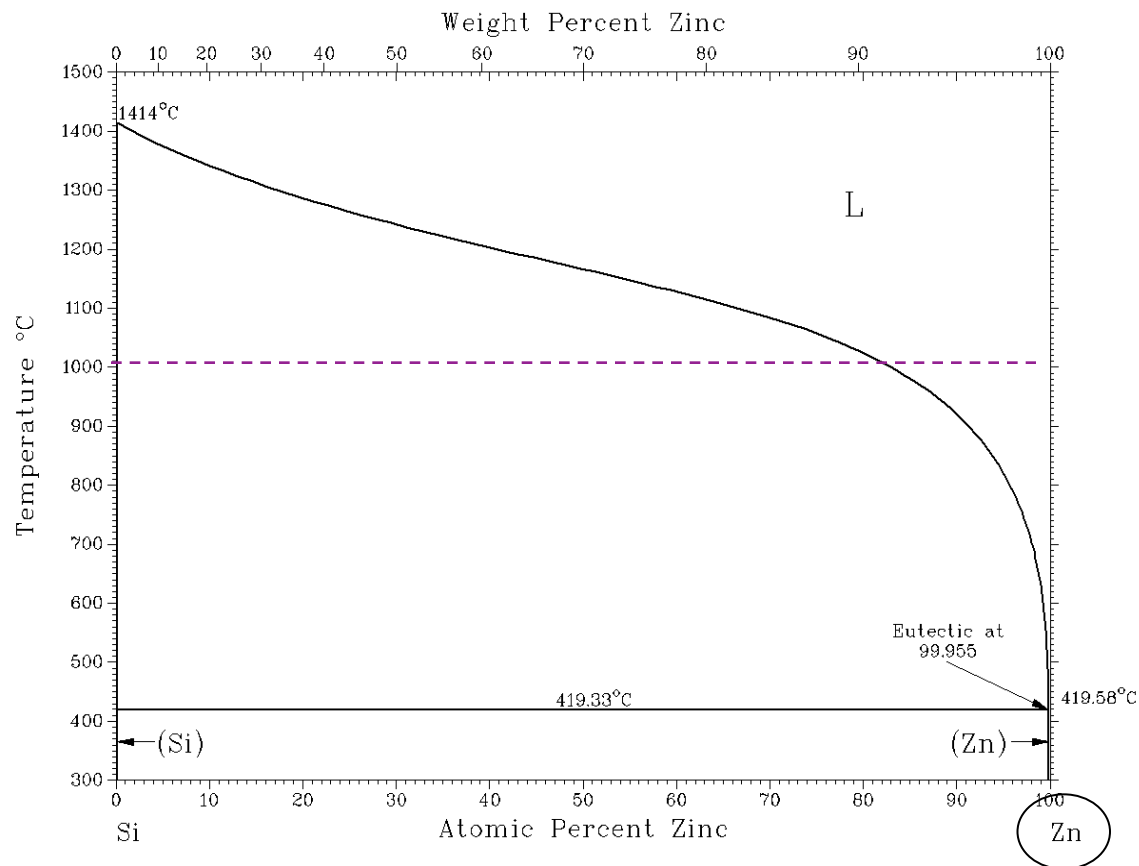
|                                      |                                      |   |                                     |                                       |                                       |                                       |                                    |                                       |   |   |                                      |  |                                       |   |
|--------------------------------------|--------------------------------------|---|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|---------------------------------------|---|---|--------------------------------------|--|---------------------------------------|---|
| 89<br>(227)<br><b>Ac</b><br>ACTINIUM | 90<br>232.04<br><b>Th</b><br>THORIUM | 91<br>231.04<br><b>Pa</b><br>PROTACTINIUM | 92<br>238.03<br><b>U</b><br>URANIUM | 93<br>(237)<br><b>Np</b><br>NEPTUNIUM | 94<br>(244)<br><b>Pu</b><br>PLUTONIUM | 95<br>(243)<br><b>Am</b><br>AMERICIUM | 96<br>(247)<br><b>Cm</b><br>CURIUM | 97<br>(247)<br><b>Bk</b><br>BERKELIUM | 98<br>(251)<br><b>Cf</b><br>CALIFORNIUM | 99<br>(252)<br><b>Es</b><br>EINSTEINIUM | 100<br>(257)<br><b>Fm</b><br>FERMIUM | 101<br>(258)<br><b>Md</b><br>MENDELEVIUM | 102<br>(259)<br><b>No</b><br>NOBELIUM | 103<br>(262)<br><b>Lr</b><br>LAWRENCIUM |
|--------------------------------------|--------------------------------------|---|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|---------------------------------------|---|---|--------------------------------------|--|---------------------------------------|---|

## □ What are some examples?

### (I) How to make Si? ( $T_{\text{melt}} = 1412\text{ }^{\circ}\text{C}$ )

Let's aim for max temperature of our furnace of  $\sim 1000\text{ }^{\circ}\text{C}$

Look up solvents that are low melting: Bi, Sn, Zn, Ga, Al



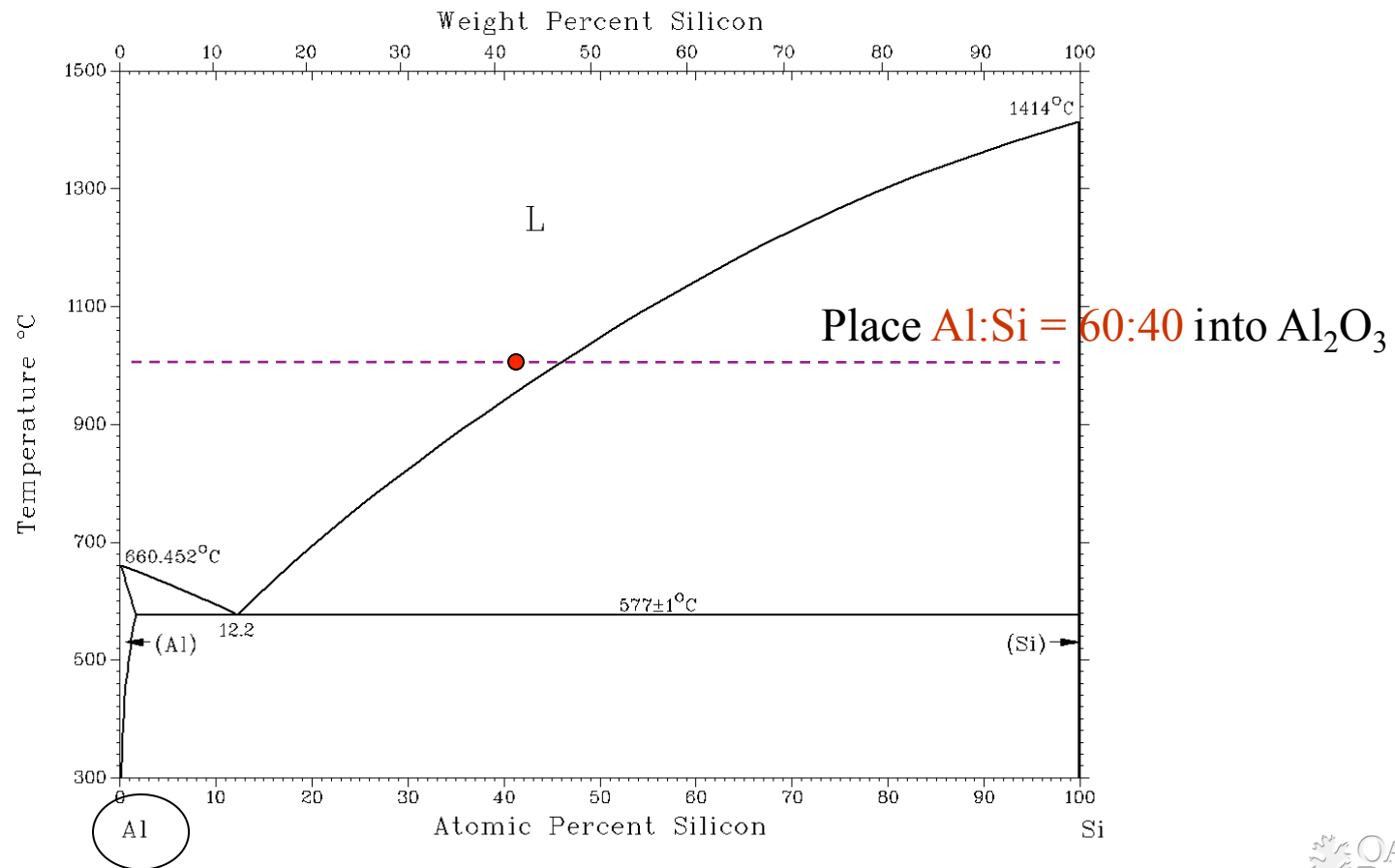
## □ What are some examples?

(1) How to make Si? ( $T_{\text{melt}} = 1412\text{ }^{\circ}\text{C}$ )

Let's aim for max temperature of our furnace of  $\sim 1000\text{ }^{\circ}\text{C}$

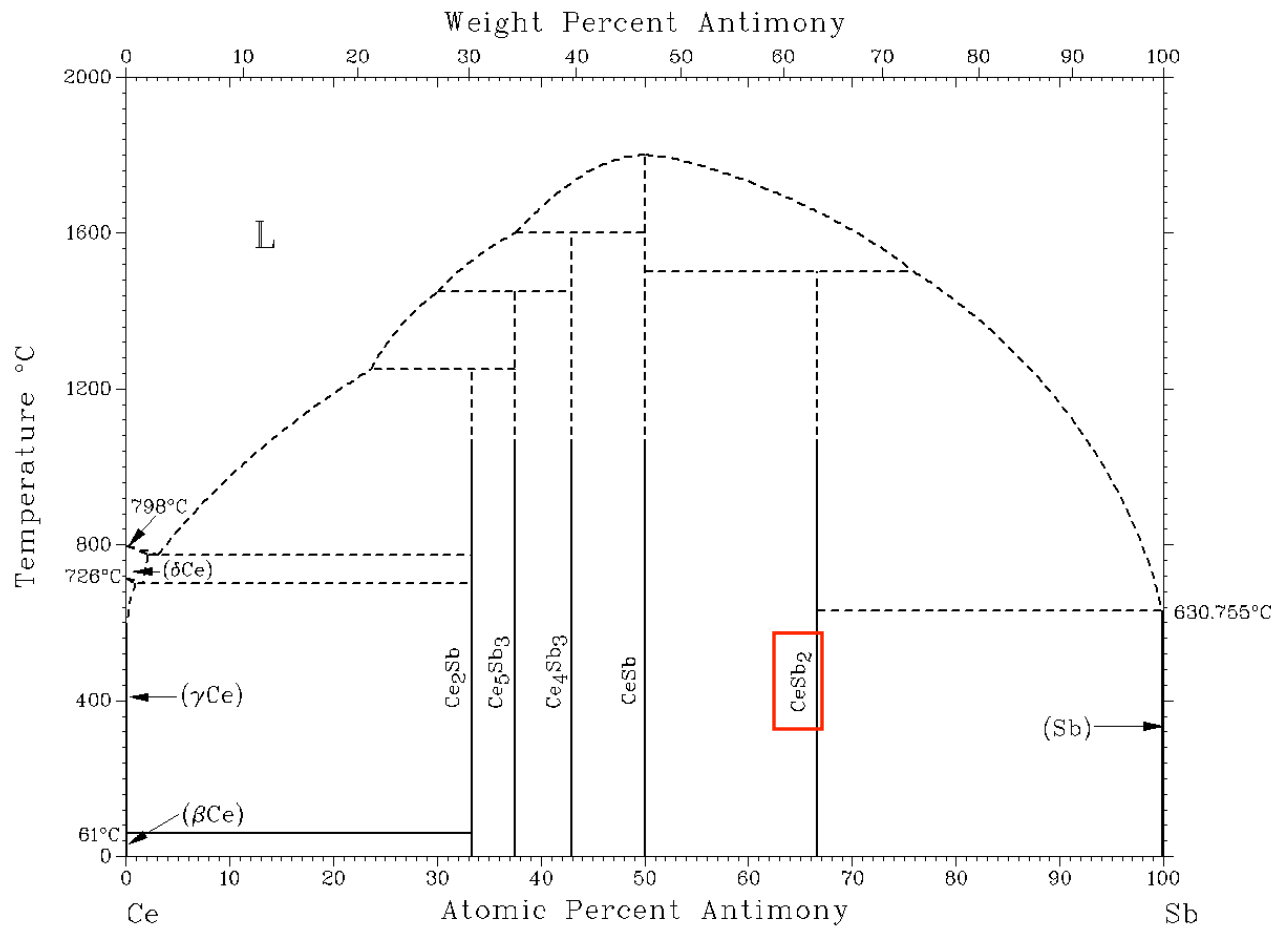
Look up solvents that are low melting: Bi, Sn, Zn, Ga, **Al**

Best solvent



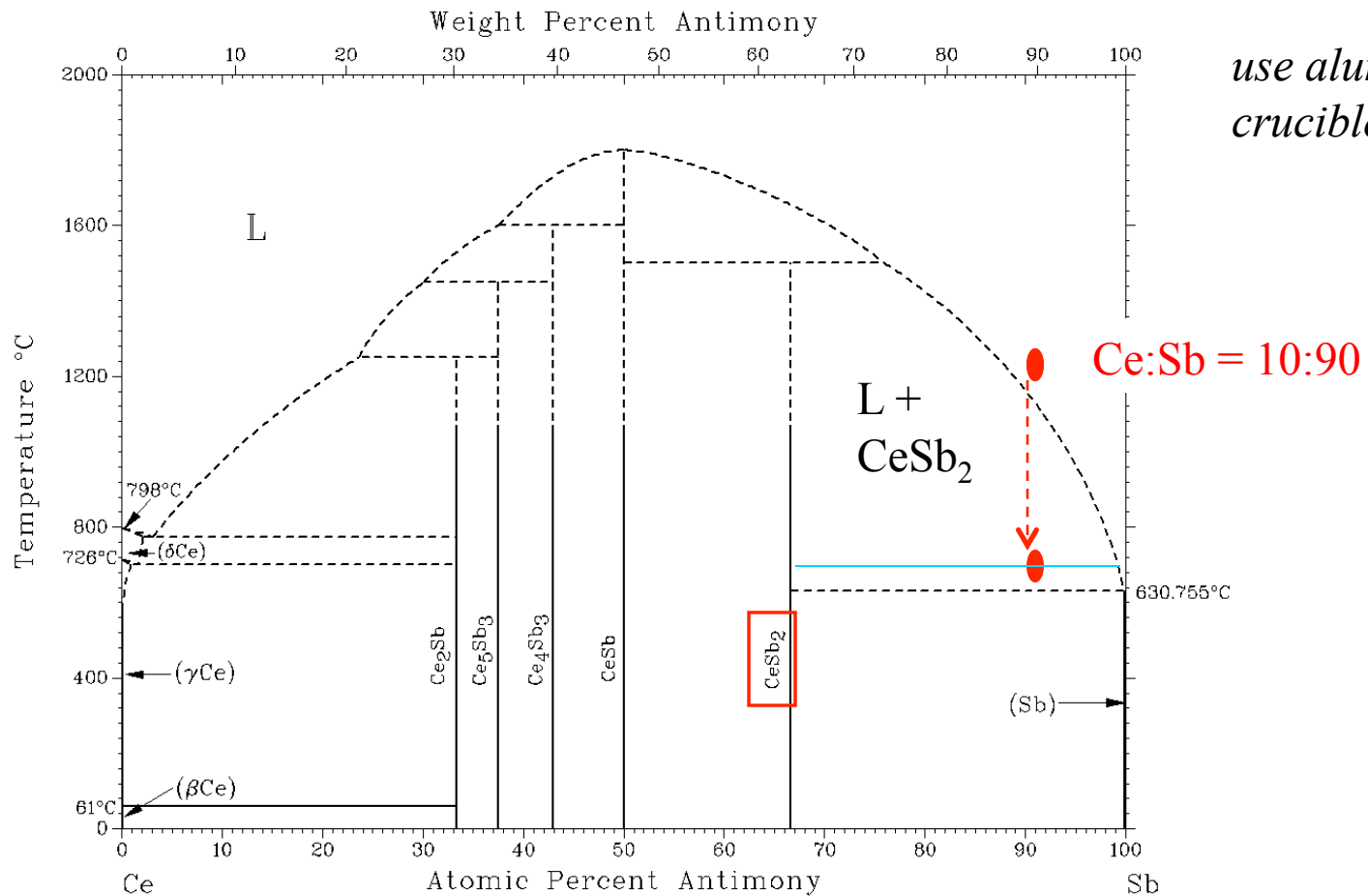
## □ What are some examples?

(2) How to make  $\text{CeSb}_2$ ? Melts incongruently



## □ What are some examples?

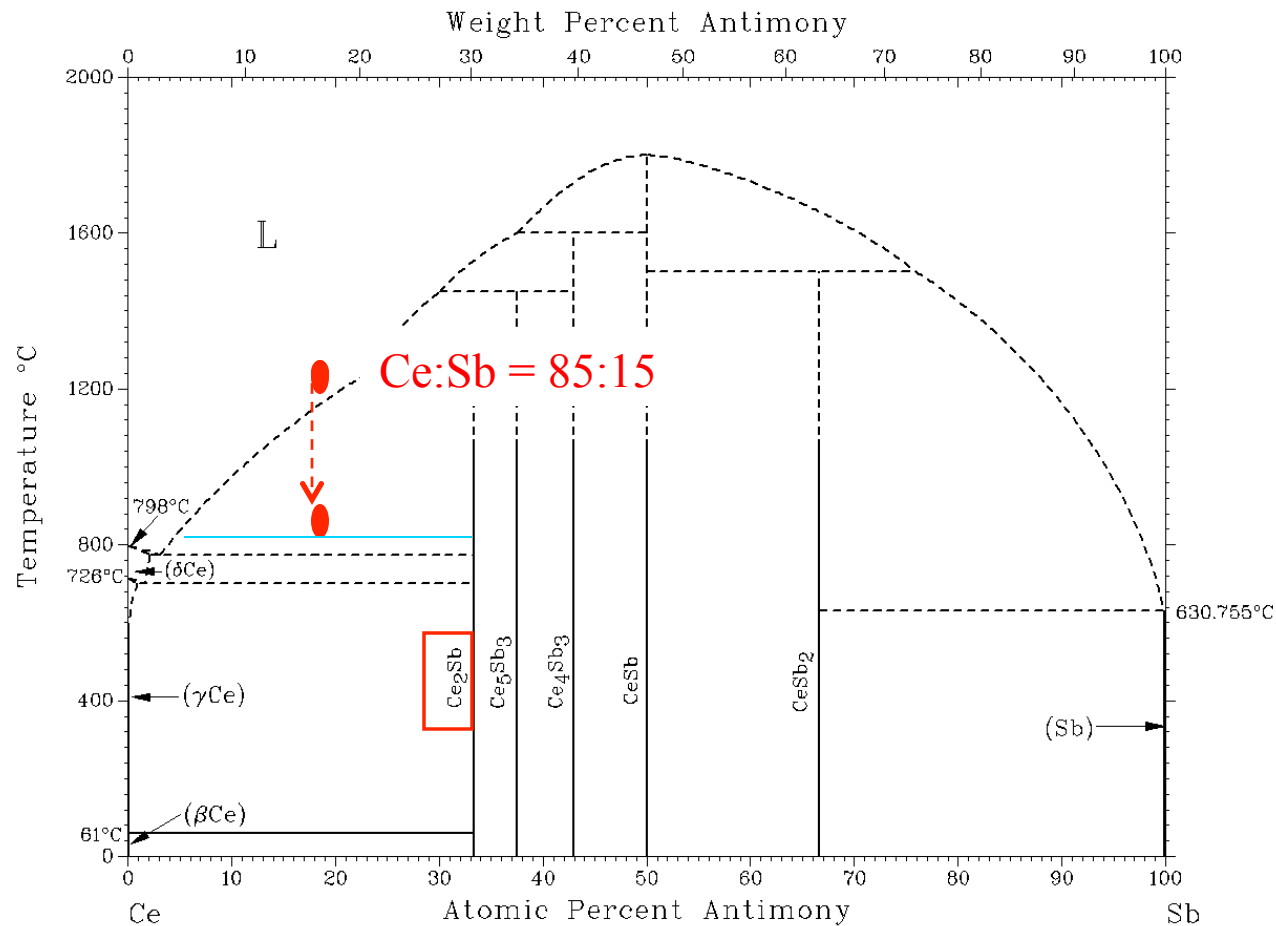
(2) How to make  $\text{CeSb}_2$ ? Melts incongruently





## □ What are some examples?

(3) How to make  $\text{Ce}_2\text{Sb}$ ? Melts incongruently

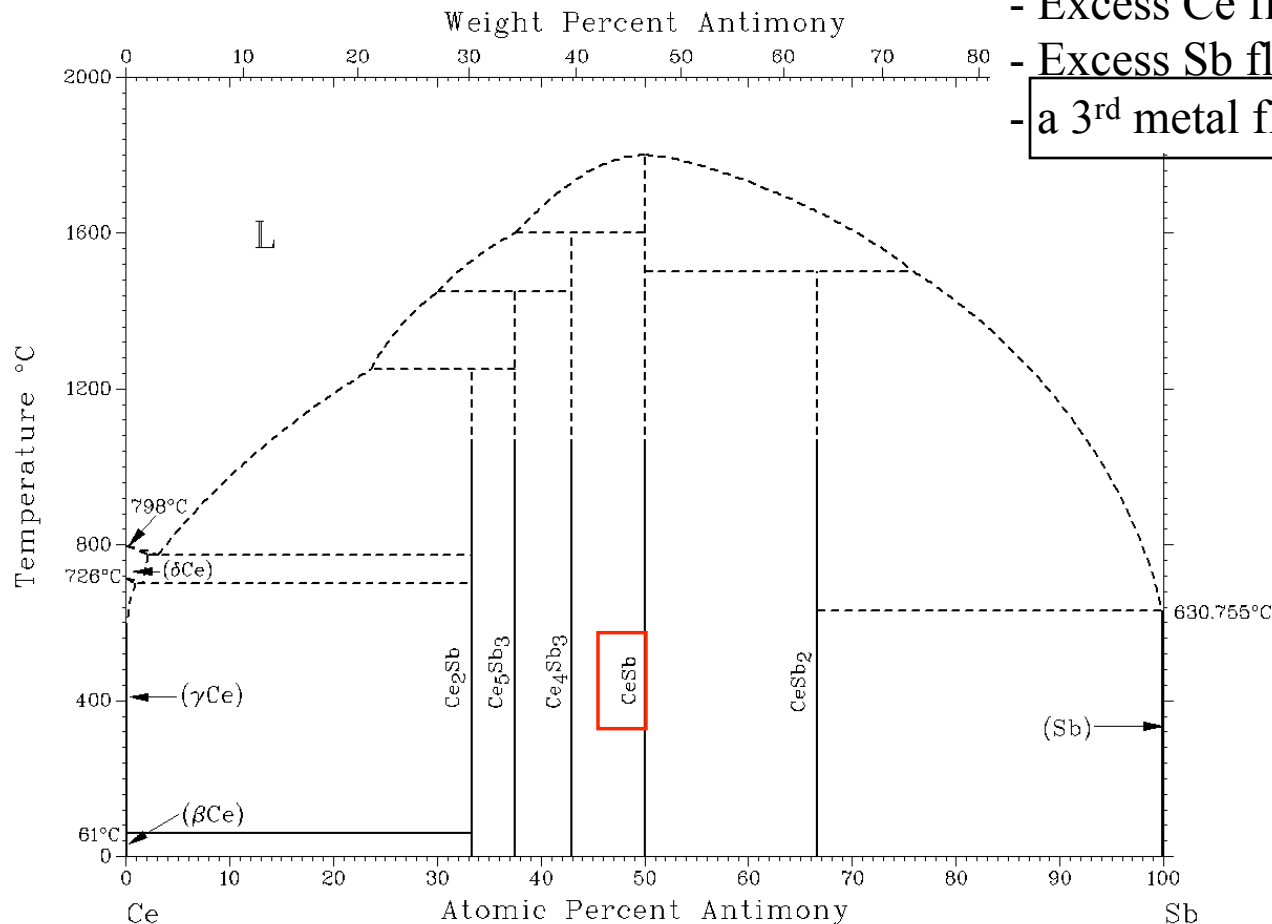


*use Ta  
crucible*

## □ What are some examples?

(4) How to make CeSb? Melts congruently at 1820 °C

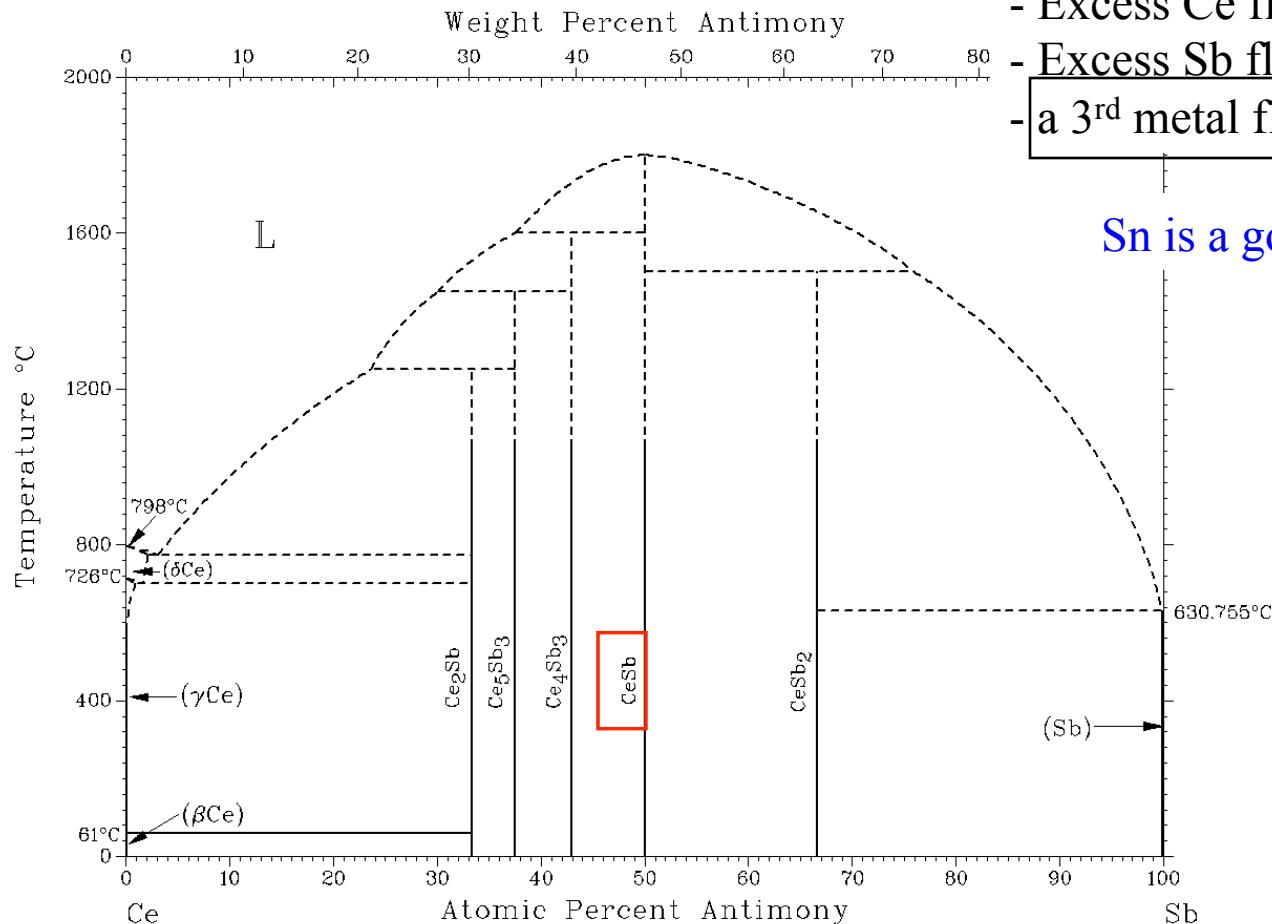
- Melt growth technique
- Excess Ce flux
- Excess Sb flux
- a 3<sup>rd</sup> metal flux?



## □ What are some examples?

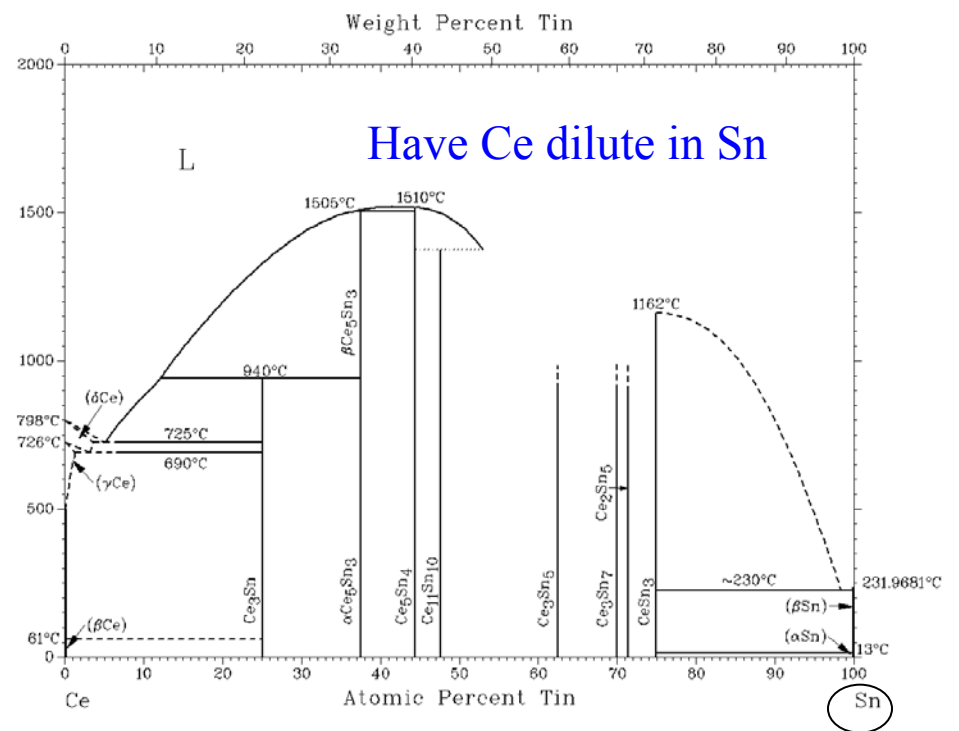
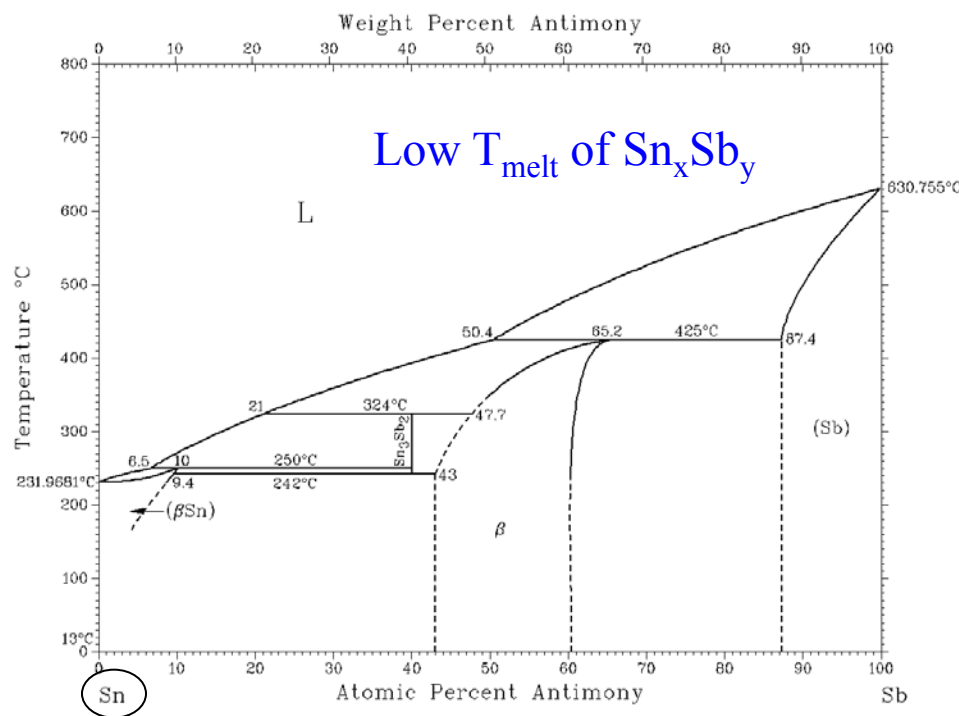
(4) How to make CeSb? Melts congruently at 1820 °C

- Melt growth technique
- Excess Ce flux
- Excess Sb flux
- a 3<sup>rd</sup> metal flux?

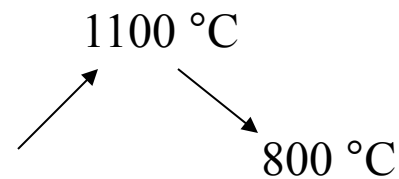


Sn is a good choice

- Sn is a low-melting element that offered good solubility for both Sb and Ce



e.g. Try Ce:Sb:Sn = 5:5:95



## □ What are some of my research examples?

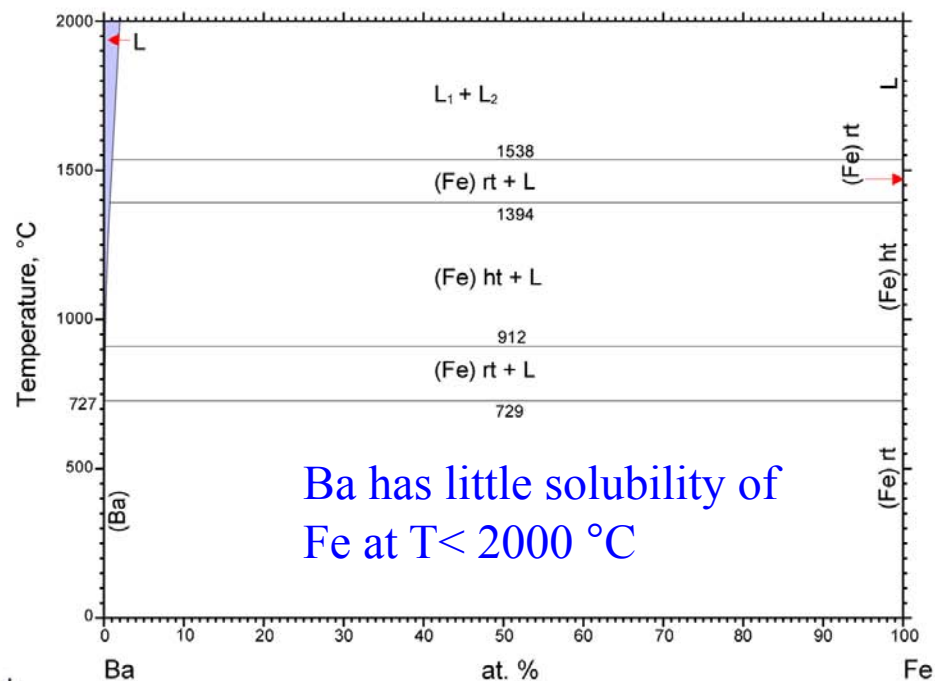
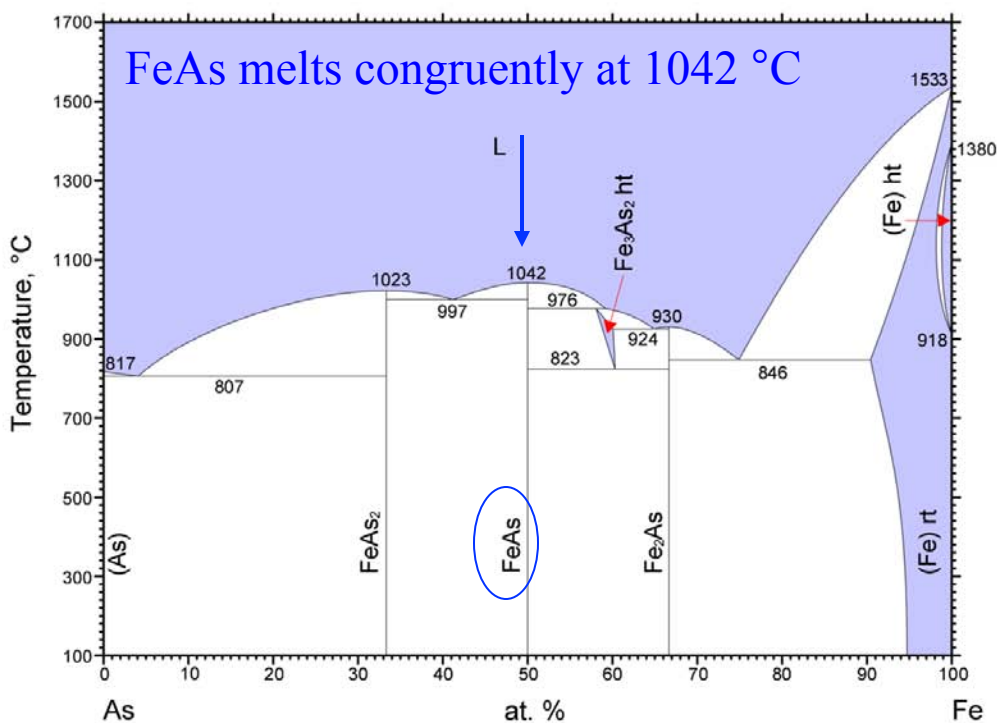
### *Growth of $BaFe_2As_2$*

- Ternary phase diagram not known
- Arsenic has a high vapor pressure ( $\sim 600^\circ\text{C}$ , 1 atm)
- Look for binary phase diagrams: Ba-Fe, Fe-As, Ba-As



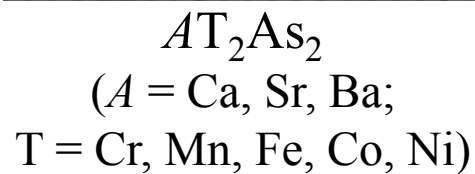
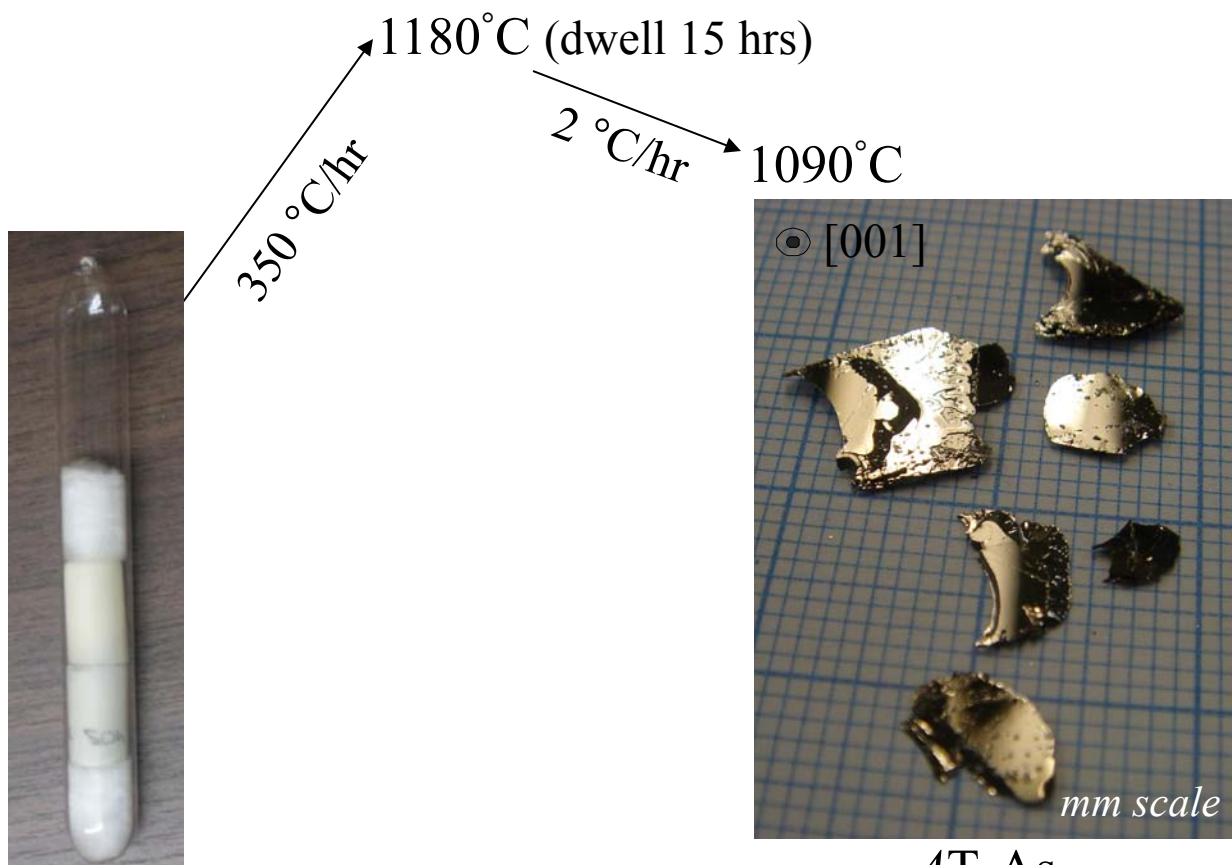
1<sup>st</sup>, make FeAs

30 °C/hr → 700 °C (dwell 6 hrs)  
 60 °C/hr → 1065 °C (10 hrs)



No Atomic % Diagram for Ba-As

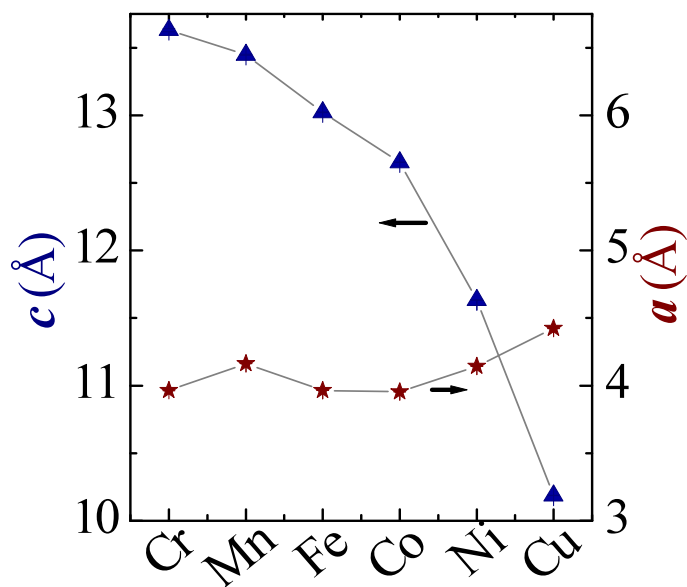
2<sup>nd</sup>, put Ba(FeAs)<sub>5</sub> in alumina crucible, in silica



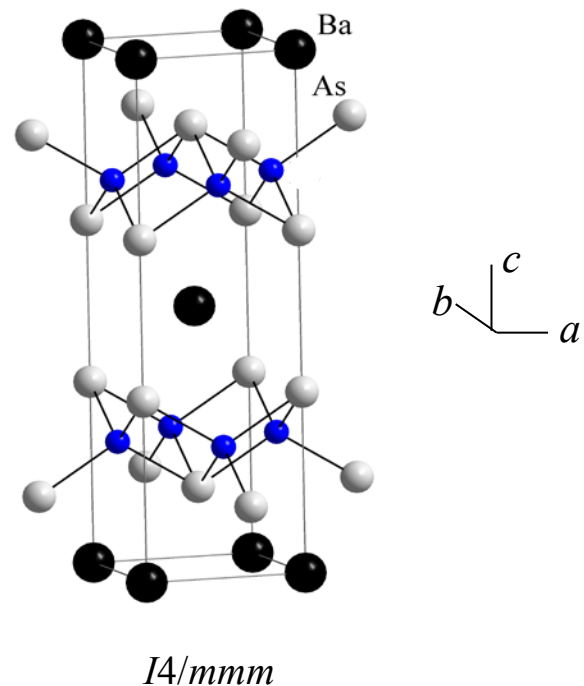
*Phys. Rev. Lett.* **101**, 117004 (2008).  
*Physica C* **469**, 350 (2009).



|    |    |    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|----|----|
| 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| K  | Ca | Sc | Ti | V  | Cr | Mn | Fe | Co | Ni | Cu | Zn |

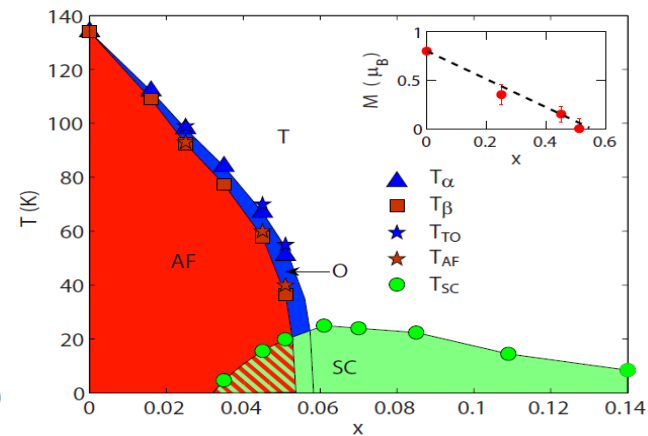
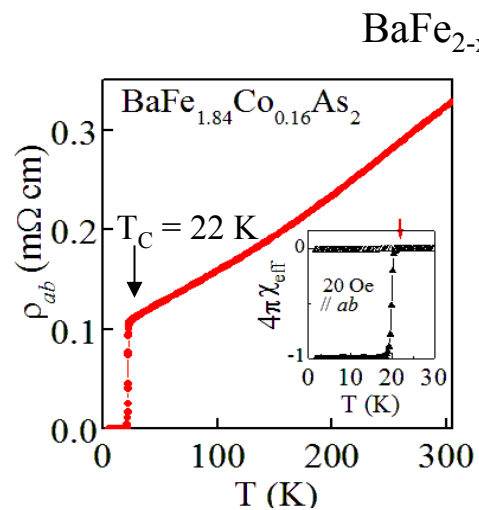
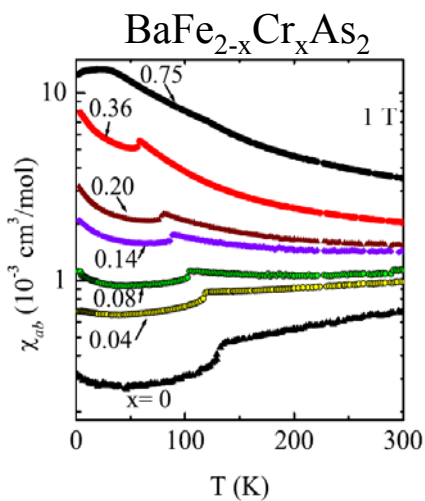
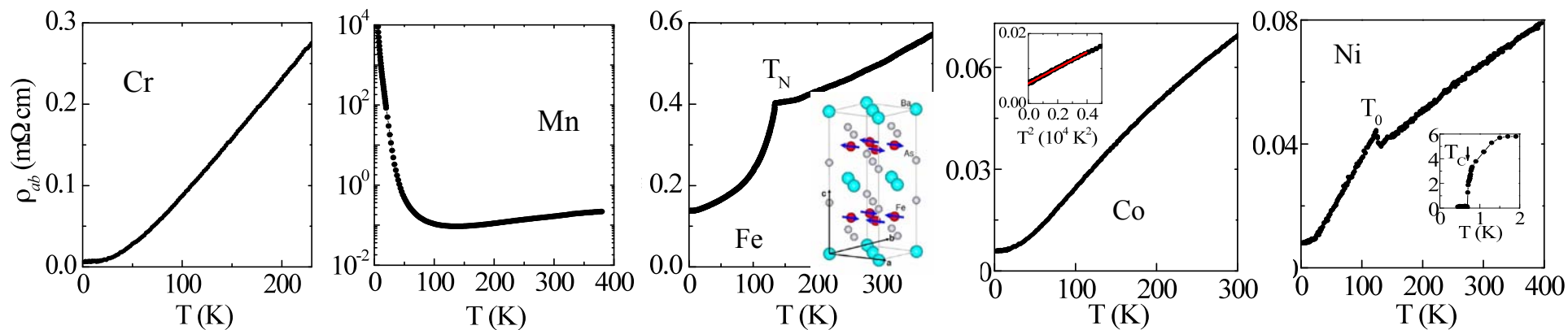


~ 7.4 % volume collapse



Z. Naturforsch. B 36 (1981), 1668.

# BaT<sub>2</sub>As<sub>2</sub>



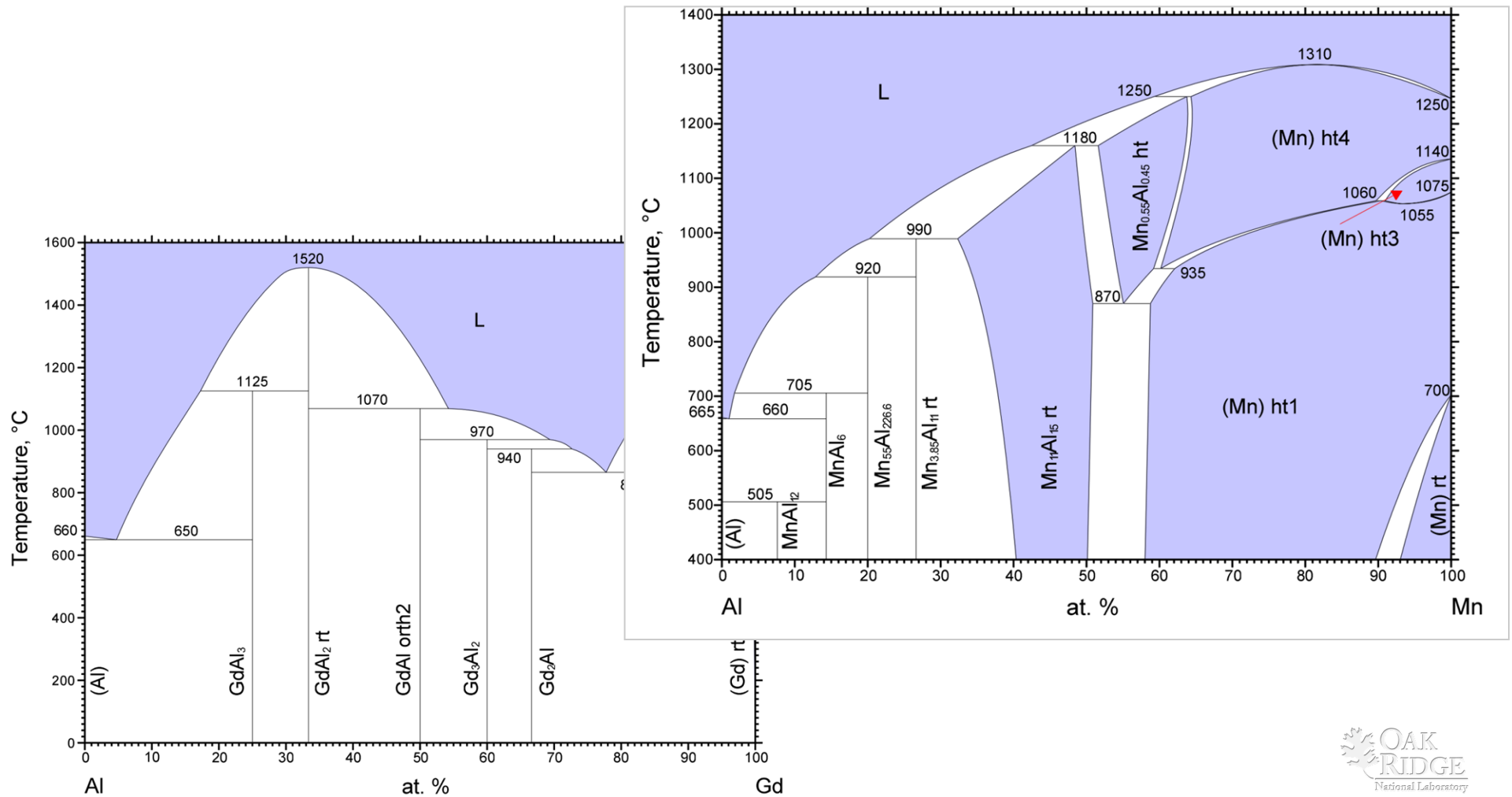
*Phys. Rev. Lett.* **101**, 117004 (2008).

*Phys. Rev. B* **79**, 024512; 094429; 224524; 144523 (2009).

*Physica C* **469**, 350 (2009).

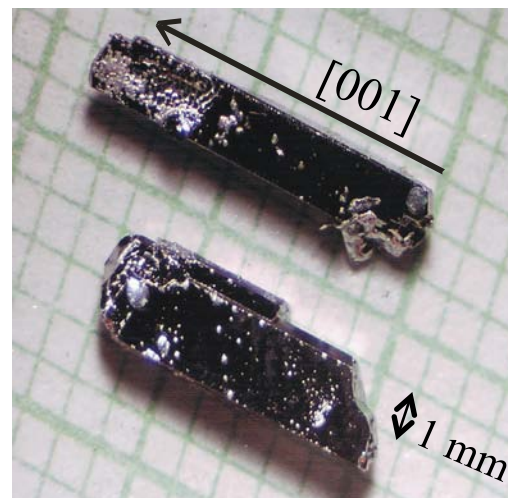
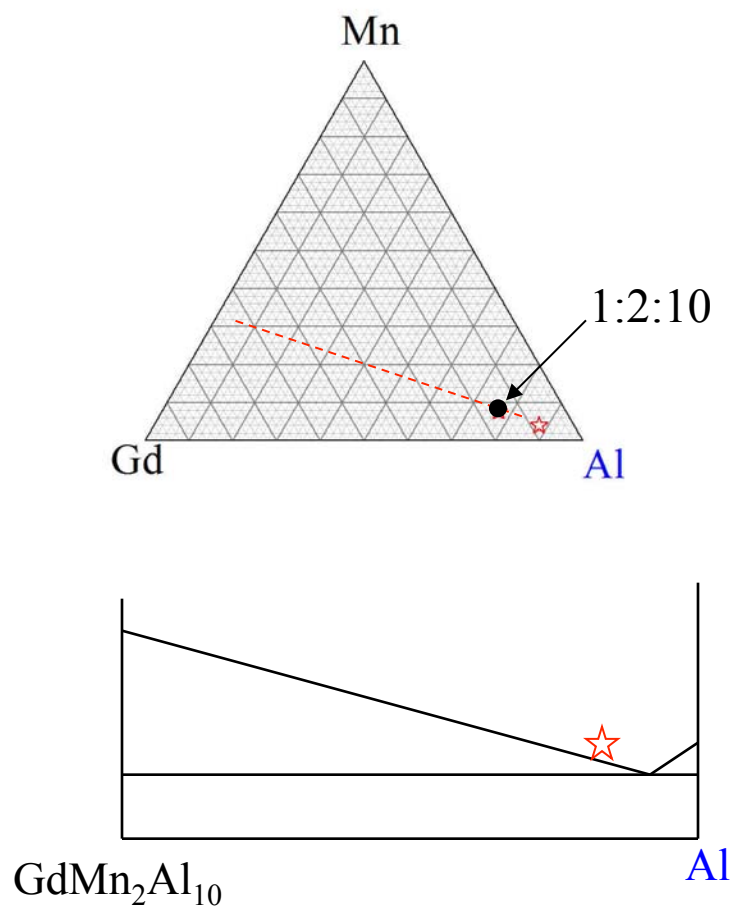
# Growth of $\text{GdMn}_2\text{Al}_{10}$

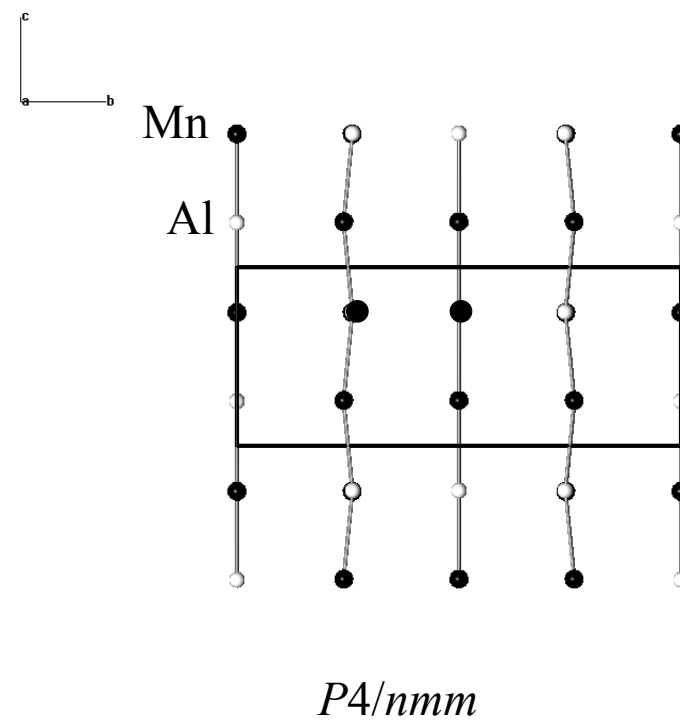
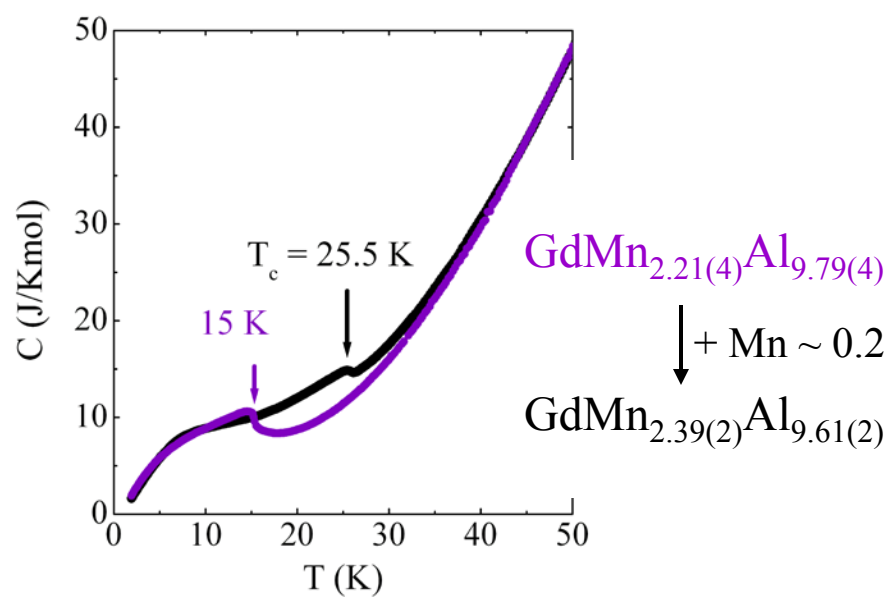
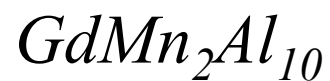
- Ternary phase diagram not known





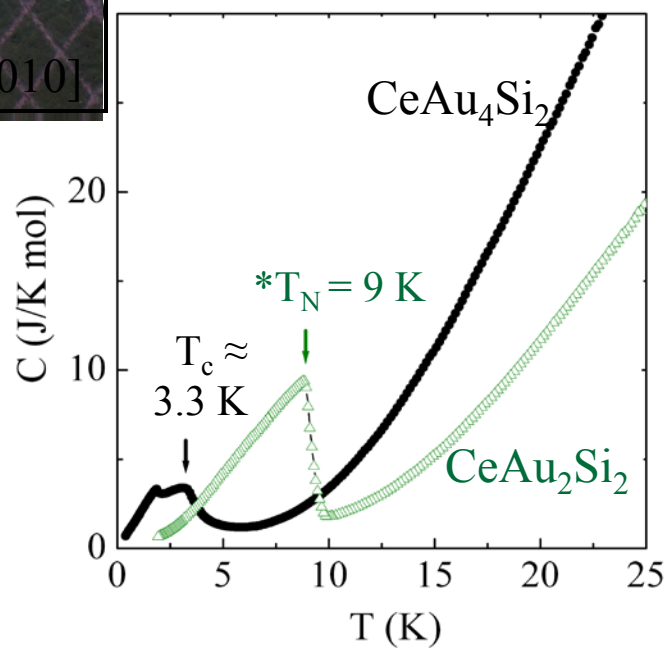
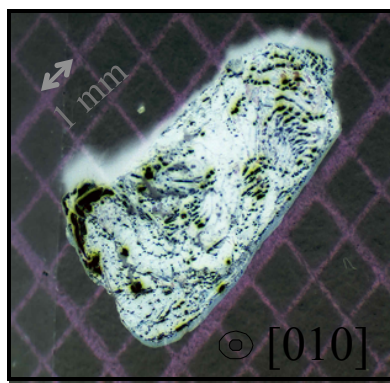
Try Gd:Mn:Al = 0.04: 0.08: 0.88 ☆





*Z. Naturforsch.* **53b** (1998), 673.  
*Phys. Rev. B* **76** (2007), 174419.

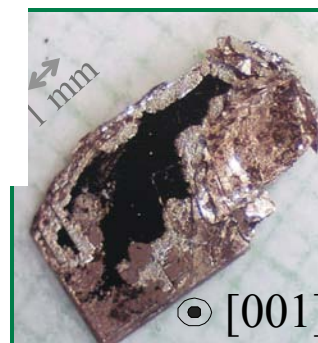
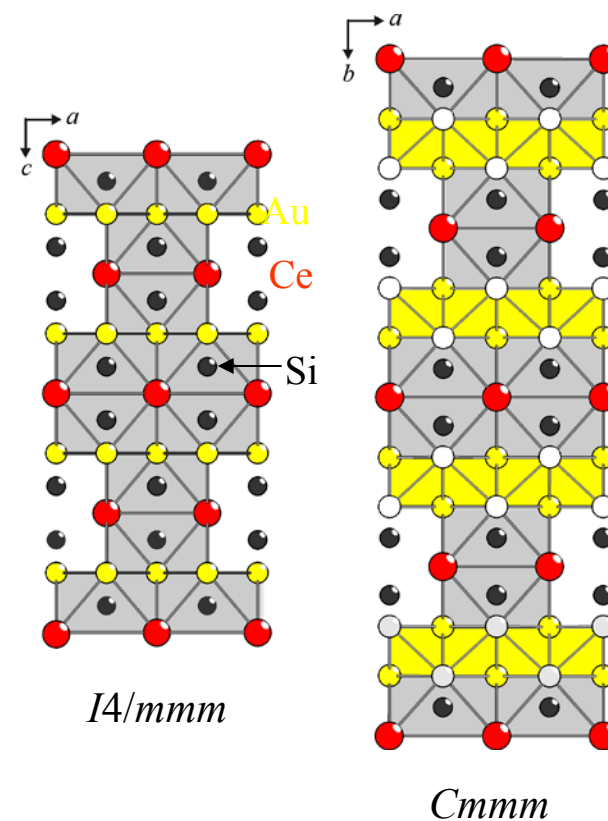
# Growth of $CeAu_xSi_2$

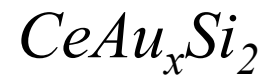


\*  $T_N = 4$  K, 8.1 K

*Physica B*, 378 (2006), 812

*J. Magn. Mag. Mater* 272-276 (2004), e405.

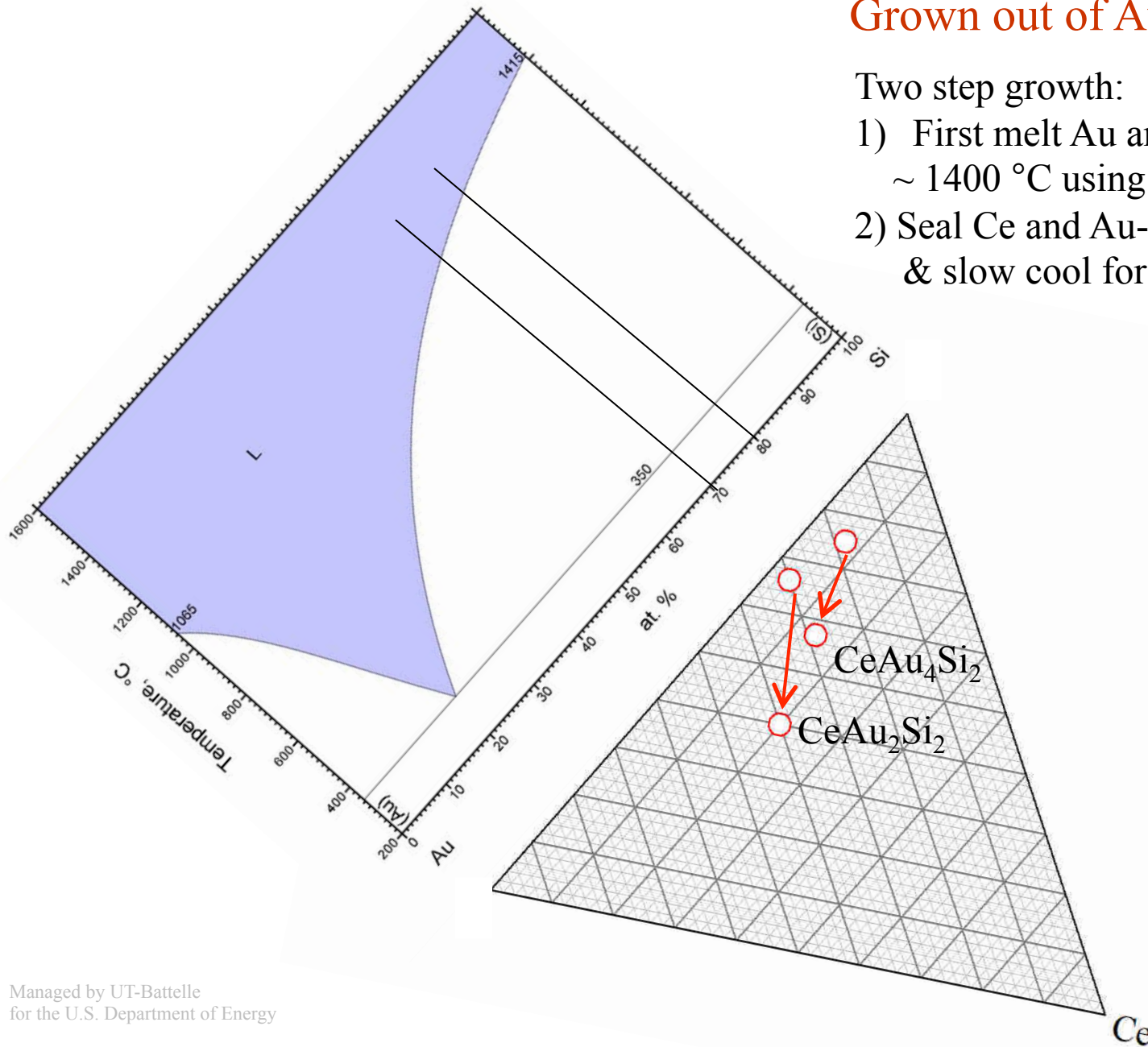




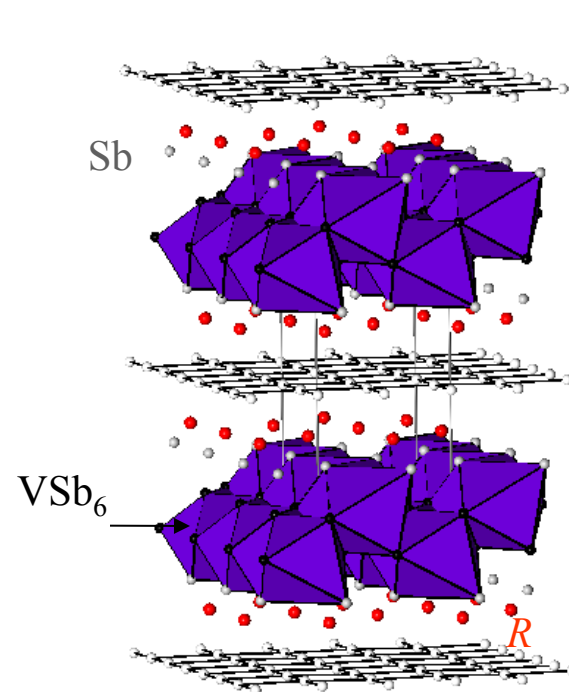
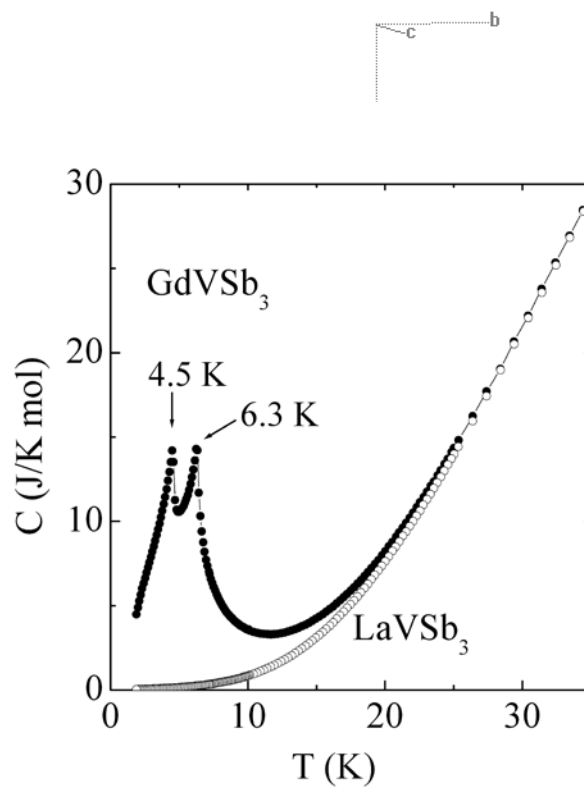
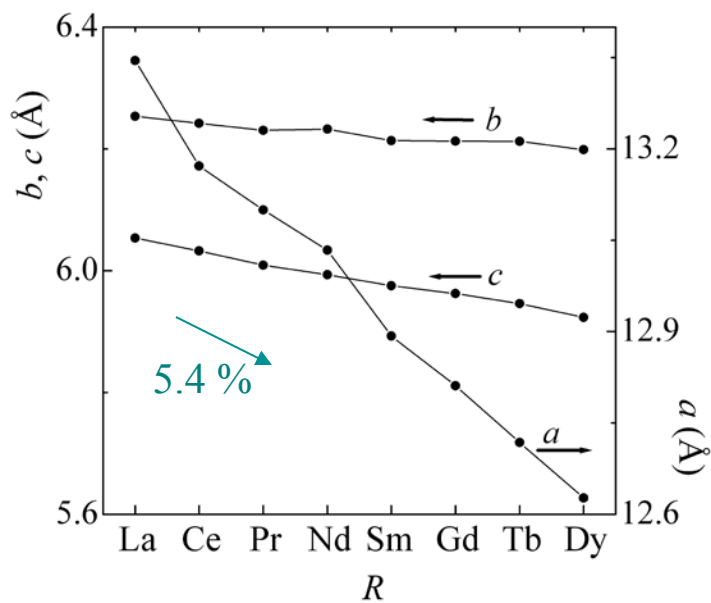
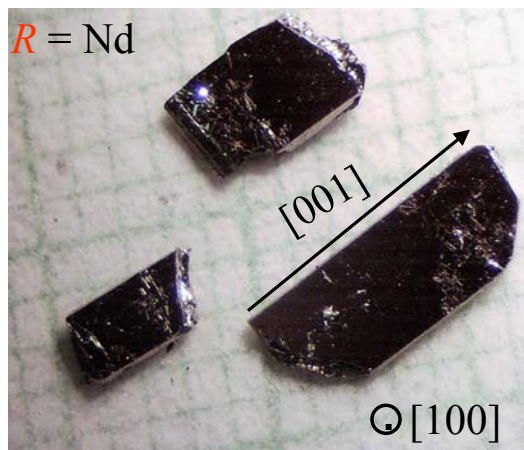
Grown out of Au-Si eutectic

Two step growth:

- 1) First melt Au and Si together at  $\sim 1400^\circ\text{C}$  using an arc melt
- 2) Seal Ce and Au-Si in silica, soak & slow cool for crystal growth



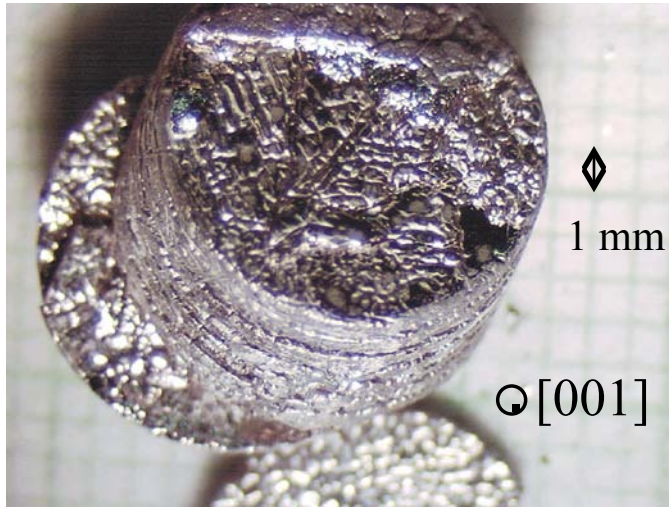
# Growth of $RV\text{Sb}_3$



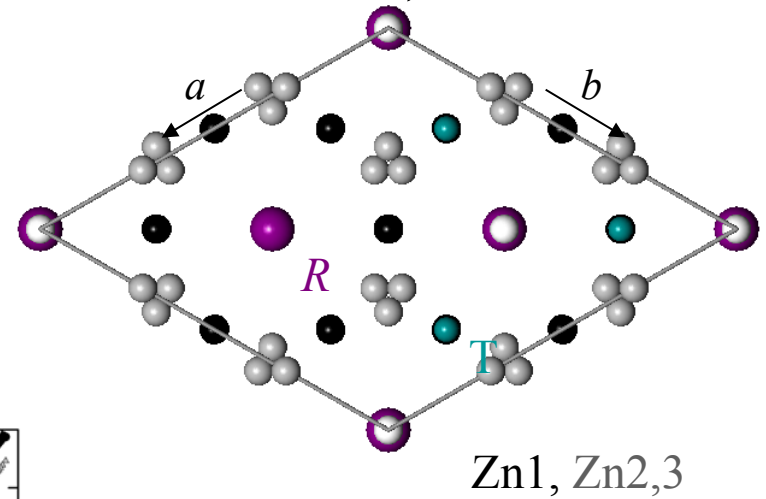
*Phys. Rev. B*, 65 (2001), 014421.  
*J. Magn. Mag. Mater.* **320**, 120 (2008).



# Growth of $R_2Co_3Zn_{14}$

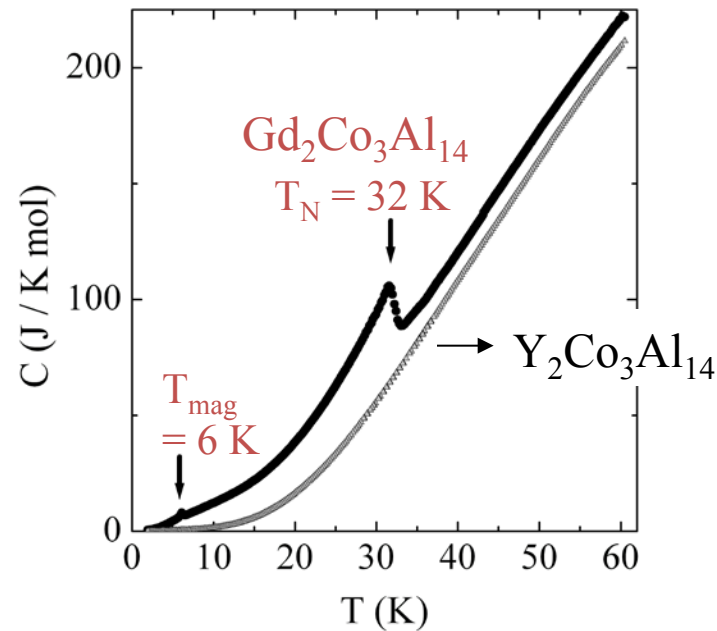


Initial melt of  $R:Co:Zn = 8:12:80; 6:11:83$



$R = Gd, T = Co$

*J. Magn. Mag. Mater.*  
**320**, (2008), 1035.



$R-3m$   
*Chem. Mater.* **14** (2002), 2725.

## Concluding remarks:

- You can try to discover, and design that allow you to pursue the specific science that interest you.
- Although flux growth technique is less predictable than conventional crystal growth methods, the discovery of new materials may be made unexpectedly!
- Hope that you want to get in a synthesis lab and attempt crystal growth!