先端科学技術セミナー

# 極限環境下の物質科学

## ―金属水素は室温超伝導になるか―

極限科学

超伝導

大阪大学　極限量子科学研究センター
超高圧量子物性部門
清水克哉

http://hpr.cqst.osaka-u.ac.jp
shimizu@cqst.osaka-u.ac.jp

## 複合極限物性研究のめざすもの

温度(T)、圧力(P)、磁場(B)：
物理における重要な3つのパラメータ

同時に2つまたは3つ組み合わせた**極限状態での物質**の特性を研究する。

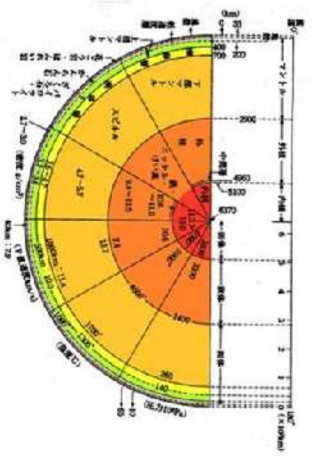
ambient～：　1気圧、15℃、0．3ガウス？
(常の～)　　常圧、常温、常・・・

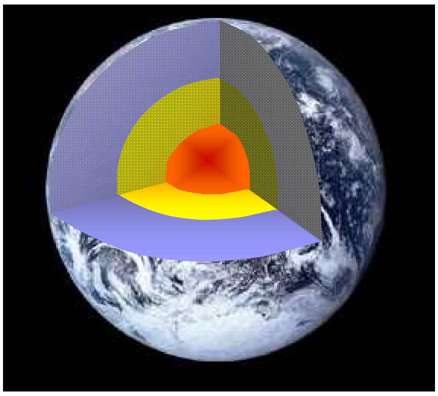
複合極限物性のめざすもの

~~異常な状態での物性研究　「重箱の隅」？~~

## 我々の地球の中身は？

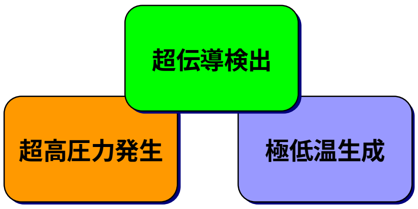
**鉄**(Fe) 35%, **酸素**(O) 30%, **シリコン**(Si) 15%, **マグネシウム**(Mg)13%, …



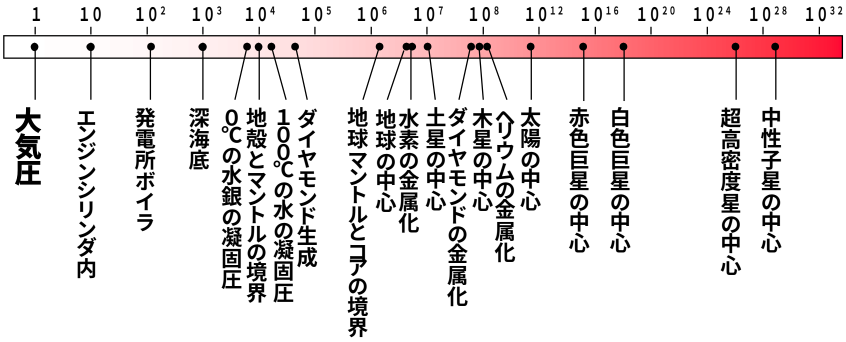


## 鉄も押せば非磁性になる

- 圧力は物質の特性を大きく変えうる。
- 非磁性金属なら冷やせば超伝導になるのでは？
- 圧力下での超伝導研究－押せばもっと高い$T_C$?
- 液体ヘリウム温度（4K）以下での高圧下物性研究の意義

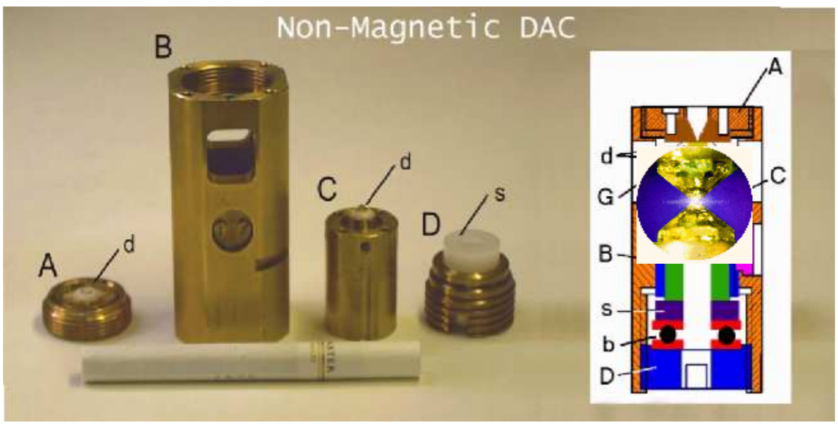


## 圧力 (気圧)



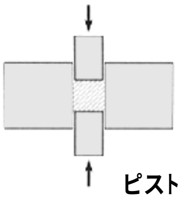

“Giga-Pascal” : 1GPa ($10^9$Pa) ＝10kbar ~ **1万気圧**

## 圧力装置：Diamond Anvil Cell (DAC)

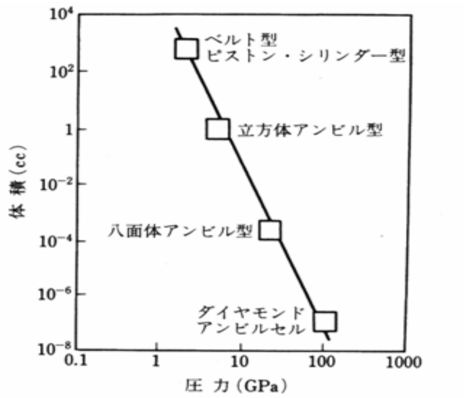



A: upper diamond holder, B: main body, C: cylinder with lower diamond,
D: loading nut, d: diamond, s: plastic ring.

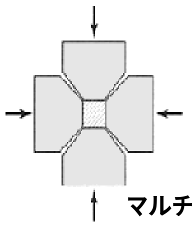
## 荷重を加える方法と発生できる圧力



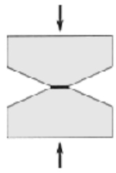
ピストン･シリンダー




各種静的圧力発生装置における内部体積と到達圧力.

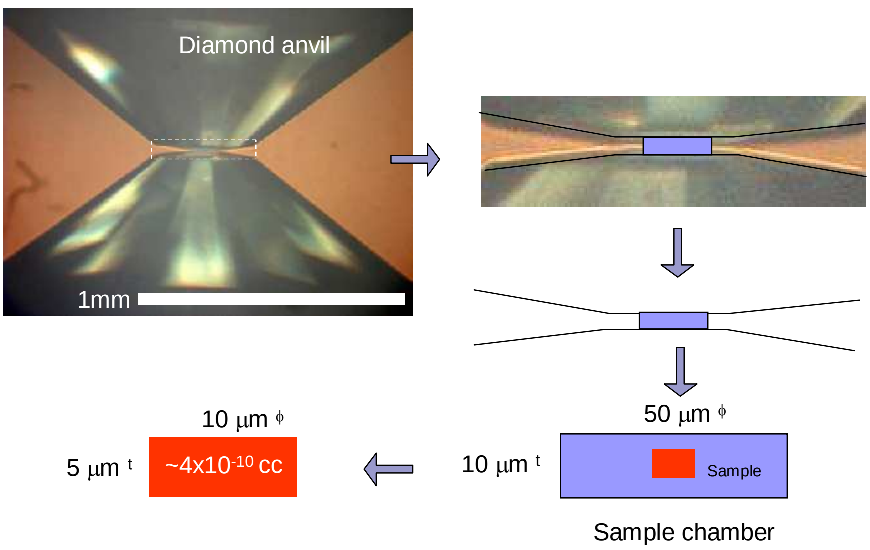


マルチアンビル



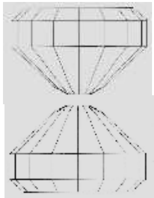
対向アンビル

## Typical size of sample at Mbar-pressure in DAC

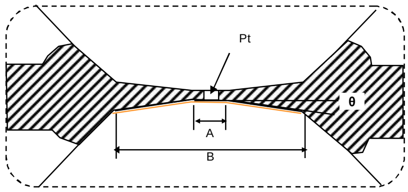


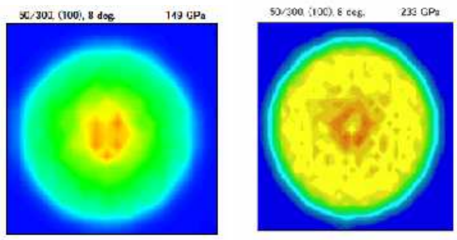
## Deformation of synthetic type IIa diamond anvils under high-pressure

Estimated from transmission coefficient of high-power x-ray beam (SPring-8, BL10X)

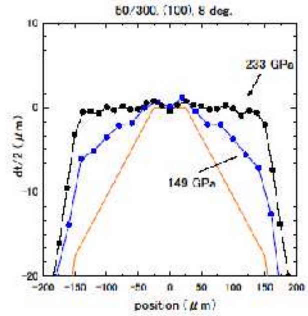


A=50 μm
B=300 μm
θ =8 deg



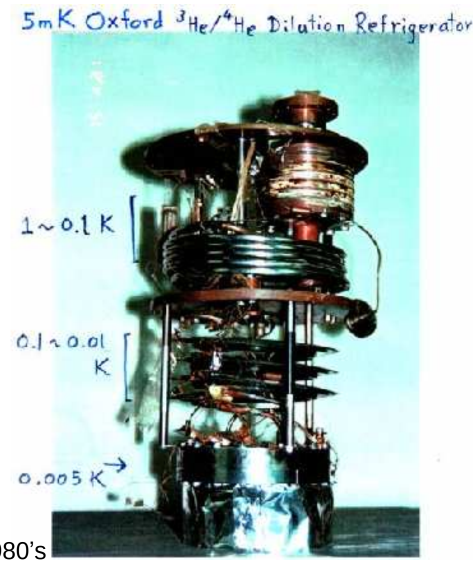




Pressure distribution on diamond surface

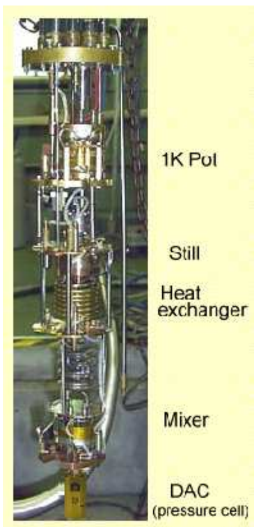



Deformation of diamond surface

## 我が国の希釈冷凍の創成期 (機)

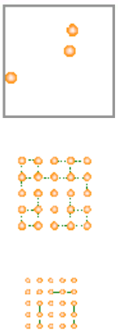



1980's




2001

## When we change *T* and/or *P*



Gas

Liquid

Solid

Insulator

(Semiconductor)

Metal

Superconductor?

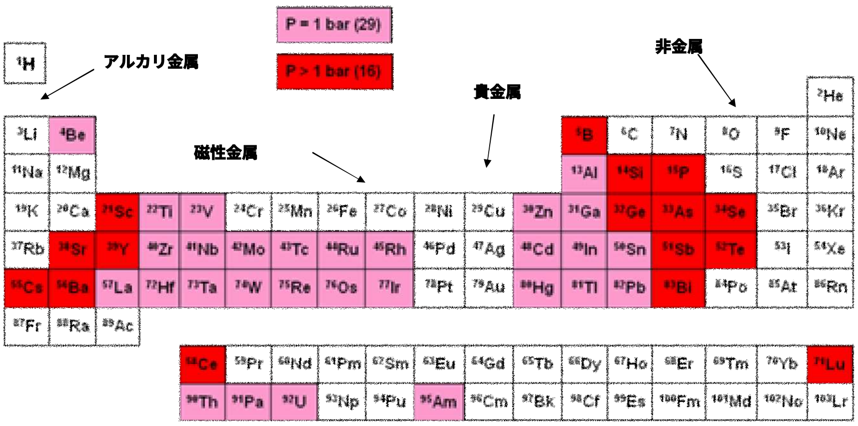
Pressurize　Cool down

**全ての物質の超高圧極限は金属であろう。**

**金属なら超伝導になってもよい環境が存在するのでは**

**なんでも超伝導？**

## 超伝導にならないものには、その理由がある

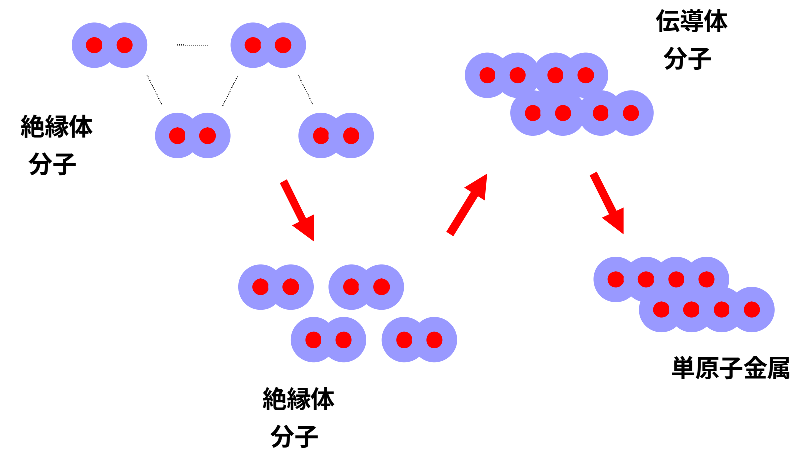



**ならない理由**　　**なる理由**

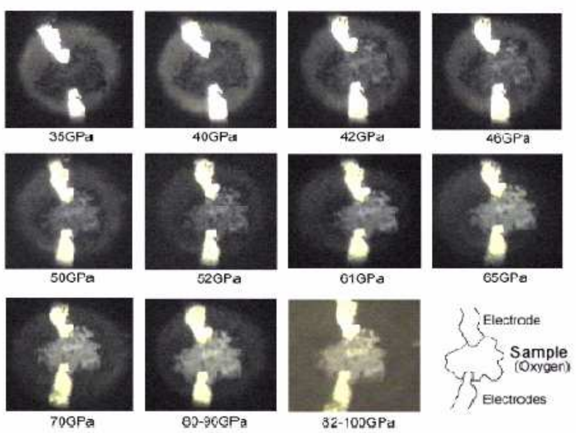
**「超伝導」の機構（しくみ）の解明**

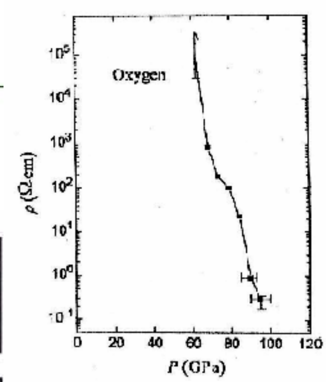
## 等核2原子分子

$H_2$、 $O_2$、 $N_2$、 $F_2$、 $Cl_2$、 $Br_2$、 $I_2$




## 高圧下の酸素　伝導性発現



## 酸素の金属化の検証

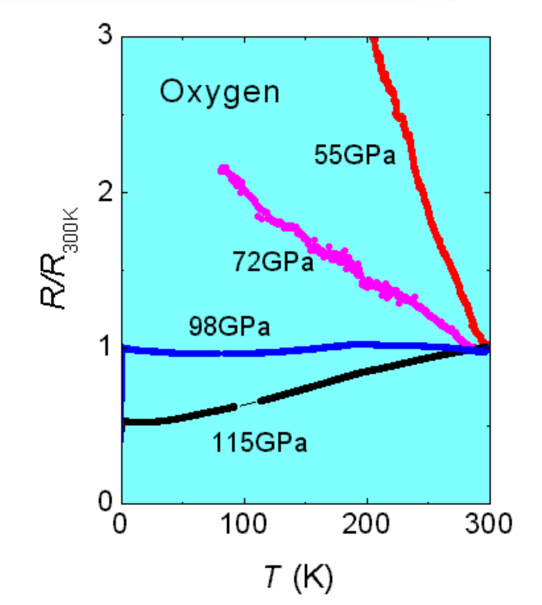
金属とは

○電気抵抗値

○展性・延性

○光る（反射）

○温度変化



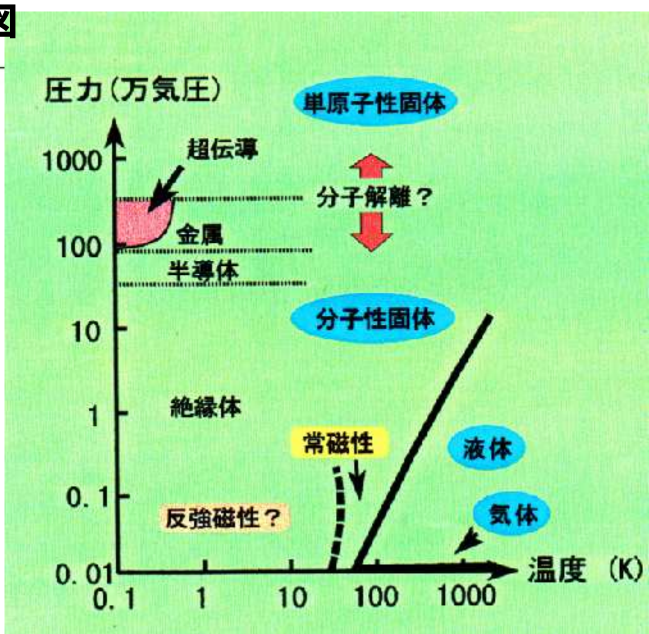

## 酸素の状態図

1．三態

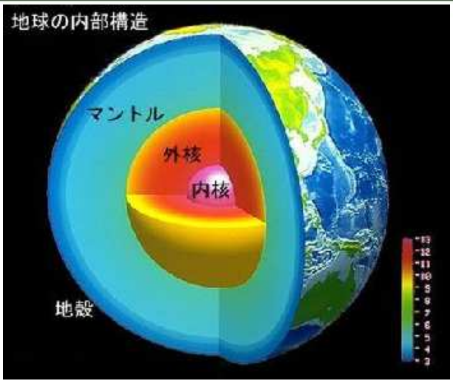
2．伝導性

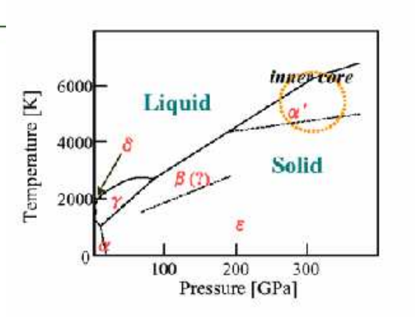
3．磁性

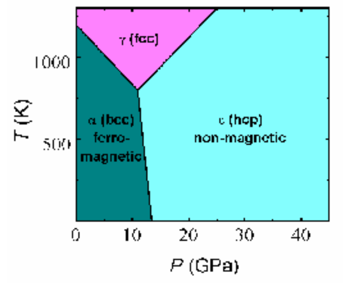
4．分子性



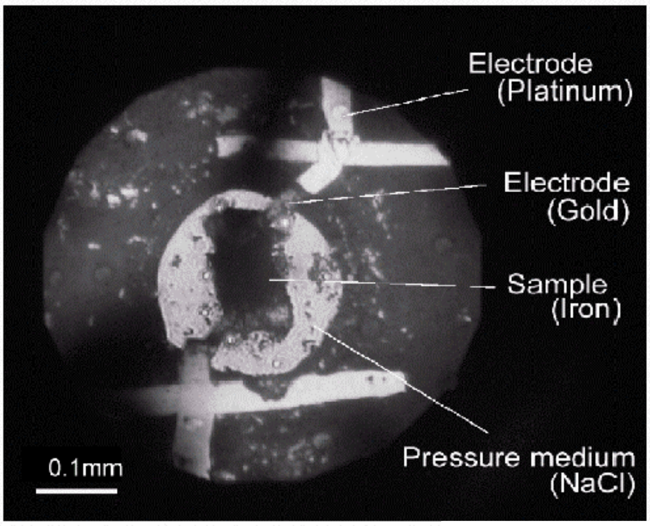
## P-T phase diagram of iron



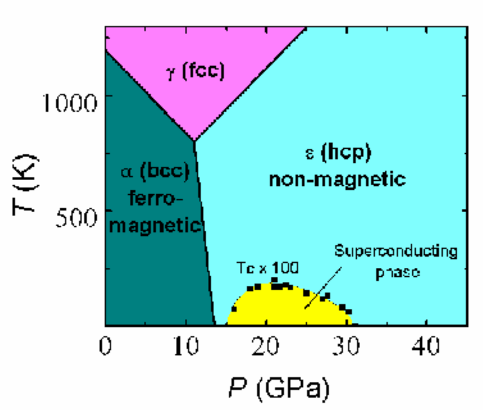

## Quasi-4 terminal measurement in quasi-hydrostatic medium



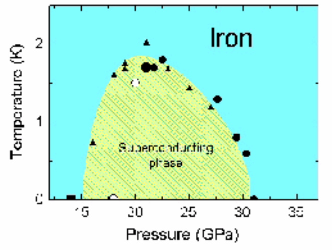

sample: 160x70x40 $\mu m^3$ gold wire: 10 $\mu m$

platinum film: 5 $\mu m^t$ diamond: 0.5mm culet

## P-T phase diagram of iron




K. Shimizu *et al*., Nature **412** (2001)316.

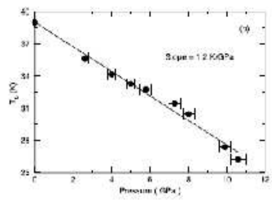



## High-$T_c$ superconductors under pressure

- $HgBa_2Ca_2Cu_3O_y$ ∼138 K
  ∼164 K (WR)

L. Gao et al., Phys. Rev. B 50, 4360 (1993).

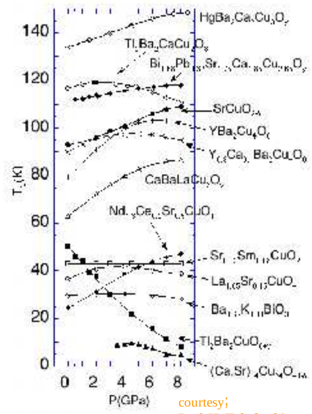
- $MgB_2$ 39 K



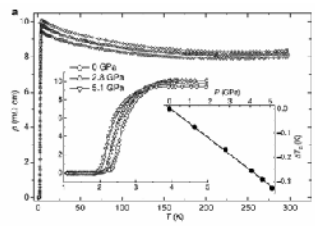
J. Nagamatsu et al., Nature 410 (2001) 63.
F. S. Razavi et al., Physica C 366 (2002) 73.

- B-doped diamond ∼12 K
- Li ∼20 K (∼50 GPa)

K. S et al., Nature 419 (2002) 597.

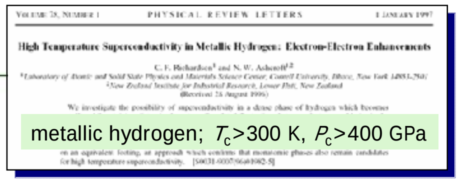



courtesy;
Prof. H. Takahashi



E. A. Ekimov al., Nature 428(2004)542.

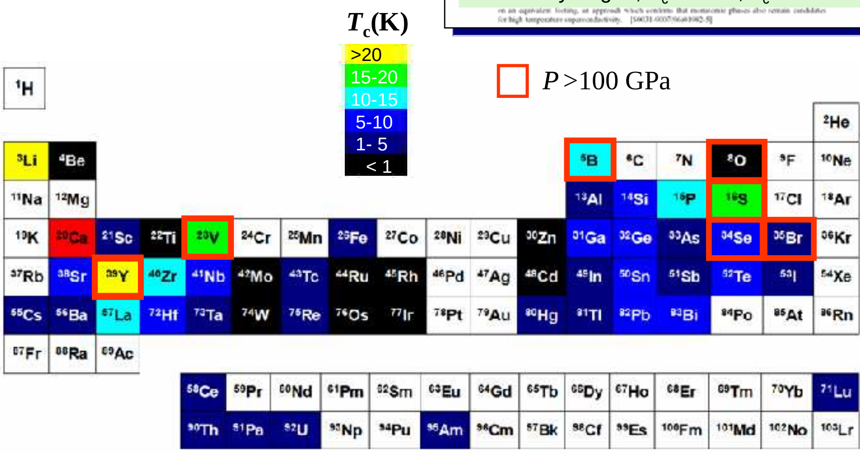
## in the case of elements...


PHYSICAL REVIEW LETTERS

**High Temperature Superconductivity in Metallic Hydrogen: Electron-Electron Enhancements**

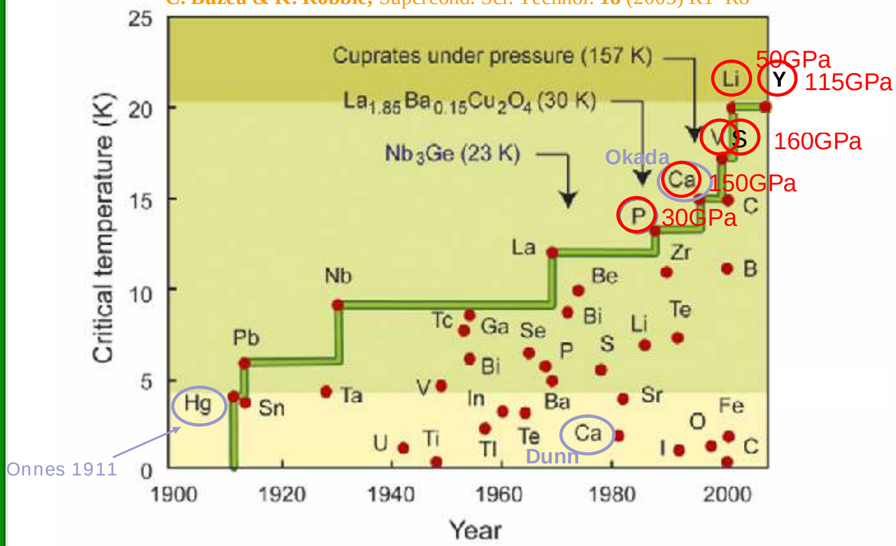
C. F. Richardson and N. W. Ashcroft

metallic hydrogen; $T_c$>300 K, $P_c$>400 GPa




## Superconducting history in elements...

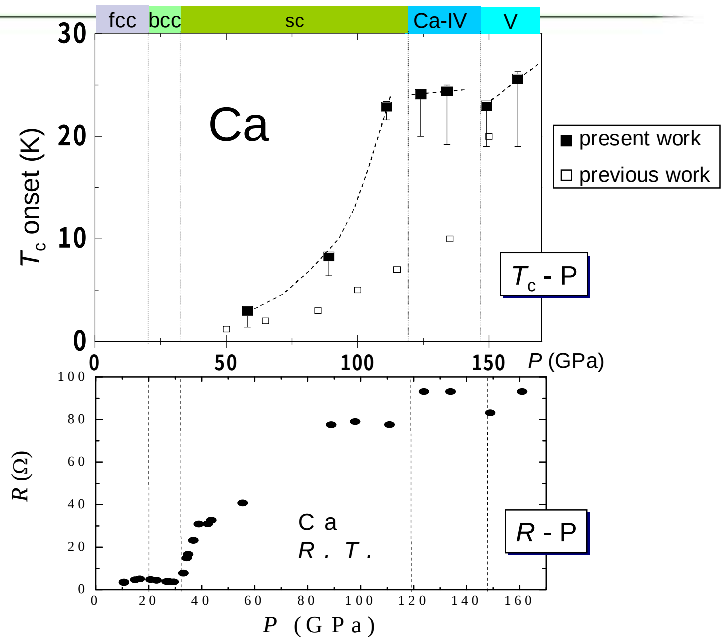
**C. Buzea & K. Robbie,** Supercond. Sci. Technol. **18** (2005) R1–R8




**K. J. Dunn and F. P. Bundy**: Phys. Rev. B **25** (1982) 194.

**S. Okada** *et al.*, J. Phys. Soc. Jpn. 65 (1996) 1924.

## Pressure dependence of $T_c$




## Summary

- Ca shows $T_c$ of 25.6 K at 161 GPa in Ca-V phase.