

Начало Лекции №1 по теории  
сверхпроводимости :  
краткое введение о различных  
сверхпроводниках

# Различные семейства сверхпроводящих материалов

Простые металлы

Elemental metals

Сплавы металлов

Metal alloys

Медь-оксидные ВТСП

Copper-oxides HTSC

MgB<sub>2</sub>

Magnesium di-boride

Железо-мышьяк

Ferro-pnictides

Рутенаты

Rhutenium-based materials

Сверхпроводники с аномально малой плотностью электронов

Extra-low-density superconductors

Двумерные сверхпроводники

2D superconductors

Сильно неупорядоченные сверхпроводники

Strognly disordered superconductors

# PERIODIC TABLE OF SUPERCONDUCTING ELEMENTS

from Yamashita T, Nakajima K, Chen J, Buzea C,  
**Superconductors - Scientific Basics and Engineering Applications**  
 (Springer-Verlag, Heidelberg) 2002 to appear

Superconducting element
  Nonsuperconducting element
  Superconducting element only under pressure or in film form

Atomic number → 4

Symbol → Be

Name → Beryllium

Critical temperature → 0.008 K

Conditions → 8 K, 8 m

Maximum critical temperature under certain conditions → 8 K

IA		IIA										IIIB		IVB		VB		VIB		VIIB		VIII	
1 H Hydrogen		3 Li Lithium 7 K 28 GPa	4 Be Beryllium 0.008 K 8 K 8 m																			2 He Helium	
11 Na Sodium	12 Mg Magnesium											5 B Boron 11.2 K 260 GPa	6 C Carbon 52 K charge doped	7 N Nitrogen	8 O Oxygen 0.5 K 100 GPa	9 F Fluorine	10 Ne Neon						
19 K Potassium	20 Ca Calcium 15 K 150 GPa	21 Sc Scandium	22 Ti Titanium 0.4 K	23 V Vanadium 5.4 K 17.2 K 120 GPa	24 Cr Chromium film	25 Mn Manganese film	26 Fe Iron 2 K 21 GPa	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc 0.85 K	31 Ga Gallium 7.8 K 0.4 K film	32 Ge Germanium 0.4 K 11.5 GPa	33 As Arsenic 2.7 K 24 GPa	34 Se Selenium 7 K 13 GPa	35 Br Bromine 1.4 K 150 GPa	36 Kr Krypton						
37 Rb Rubidium	38 Sr Strontium 4 K 50 GPa	39 Y Yttrium	40 Zr Zirconium 0.6 K	41 Nb Niobium 0.25 K 0.7 K 4.5 GPa	42 Mo Molybdenum 0.92 K	43 Tc Technetium 0.2 K	44 Ru Ruthenium 0.5 K	45 Rh Rhodium 0.005 mK	46 Pd Palladium film/film	47 Ag Silver	48 Cd Cadmium 0.52 K	49 In Indium 3.4 K 4.2 K film	50 Sn Tin 3.7 K 4.7 K film	51 Sb Antimony 3.9 K 0.5 GPa	52 Te Tellurium 7.4 K 35 GPa	53 I Iodine 1.2 K 25 GPa	54 Xe Xenon						
55 Cs Cesium 1.5 K 5 GPa	56 Ba Barium 5 K 15 GPa	72 Hf Hafnium 0.6 K	73 Ta Tantalum 4.4 K	74 W Tungsten 0.01 K 0.5 K film	75 Re Rhenium 1.7 K	76 Os Osmium 0.7 K	77 Ir Iridium 0.1 K	78 Pt Platinum	79 Au Gold	80 Hg Mercury 4.15 K	81 Tl Thallium 2.4 K	82 Pb Lead 7.2 K	83 Bi Bismuth 0.7 K 1 GPa	84 Po Polonium	85 At Astatine	86 Rn Radon							
87 Fr Francium	88 Ra Radium	57 La Lanthanum 0 K 12 K 14 GPa	58 Ce Cerium 1.7 K film	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium film	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium 0.1 K							
		89 Ac Actinium	90 Th Thorium 1.4 K	91 Pa Protactinium 1.4 K	92 U Uranium 0.7 K 2.2 K 1 GPa	93 Np Neptunium	94 Pu Plutonium	95 Am Americium 1 K	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium							

Review of superconducting properties of MgB<sub>2</sub>  
 cond-mat/0108265

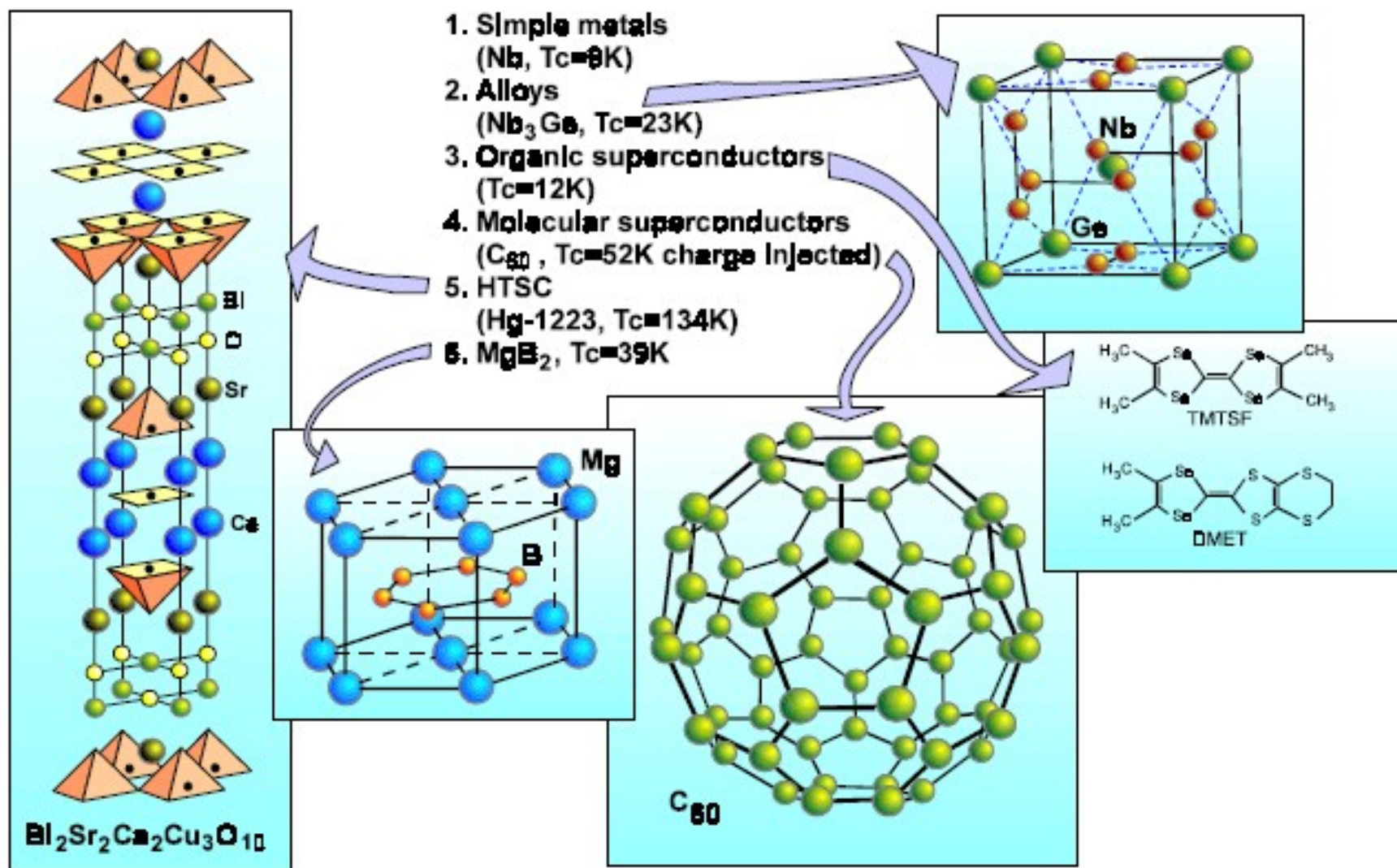


Figure 3. Comparison between the structures of different classes of superconductors

# Простые сверхпроводящие металлы - элементы

1. Критические температуры и критические магнитные поля простых сверхпроводников [10].

Элемент	$T_c$ , К	$H_{cm}(0)$ , Э
Al	$1.175 \pm 0.002$	$104.9 \pm 0.3$
Be	0.026	
Cd	$0.517 \pm 0.002$	$28 \pm 1$
Ga	$1.083 \pm 0.001$	$59.2 \pm 0.3$
Hf	0.128	
Hg ( $\alpha$ )	$4.154 \pm 0.001$	$411 \pm 2$
Hg ( $\beta$ )	3.949	339
In	$3.408 \pm 0.001$	$281.5 \pm 2$
Ir	$0.1125 \pm 0.001$	$16 \pm 0.05$
La ( $\alpha$ )	$4.88 \pm 0.02$	$800 \pm 10$
La ( $\beta$ )	$6.00 \pm 0.1$	1096, 1600
Lu	0.1	< 400
Mo	$0.915 \pm 0.005$	$96 \pm 3$
Nb	$9.25 \pm 0.02$	$2060 \pm 50$
Os	$0.66 \pm 0.03$	70
Pa	1.4	
Pb	$7.196 \pm 0.006$	$803 \pm 1$
Re	$1.697 \pm 0.006$	$200 \pm 5$
Ru	$0.49 \pm 0.015$	$69 \pm 2$
Sn	$3.722 \pm 0.001$	$305 \pm 2$

Элемент	$T_c$ , К	$H_{cm}(0)$ , Э
Ta	$4.47 \pm 0.04$	$829 \pm 6$
Tc	$7.8 \pm 0.01$	1410
Tb	$1.38 \pm 0.02$	$160 \pm 3$
Ti	$0.40 \pm 0.04$	56
Tl	$2.38 \pm 0.04$	$178 \pm 5$
V	$5.40 \pm 0.05$	1408
W	$0.0154 \pm 0.0005$	$1.15 \pm 0.03$
Zn	$0.850 \pm 0.01$	$54 \pm 0.3$
Zr	$0.61 \pm 0.15$	47



## Некоторые сверхпроводящие сплавы и соединения

Таблица 1.2. Критические температуры некоторых интерметаллических соединений и высокотемпературных сверхпроводников.

Соединение	$T_c$ , К
$Nb_3Sn$	18.1
$(Nb_3Al)_4 + Nb_3Ge$	20
$La_{0.925}Sr_{0.075}CuO_4$	34
$YBa_2Cu_3O_7$	92.4
$Bi_2Sr_2Ca_2Cu_3O_{10}$	111
$Tl_2Sr_2Ca_2Cu_3O_{10}$	123
$HgBa_2Ca_2Cu_3O_8$	133

Все это сверхпроводники  
2 рода!  
У них два разных критических поля

$$H_{c1} \ll H_{c2}$$



The Intriguing Superconductivity of Strontium Ruthenate  
<http://physicstoday.scitation.org/doi/10.1063/1.1349611>

# Экзотические материалы

The Intriguing Superconductivity of Strontium Ruthenate  
<http://physicstoday.scitation.org/doi/10.1063/1.1349611>



Iron-based superconductors (FeSC)

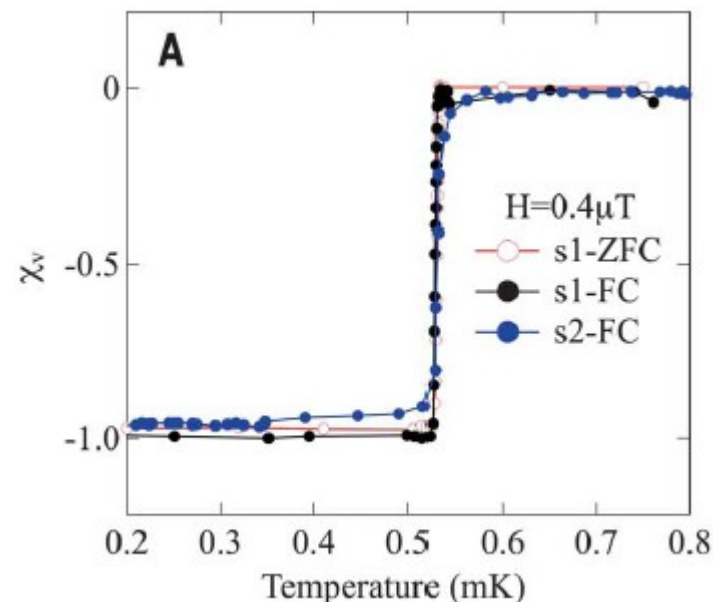
<u>Oxypnictide</u>	$T_c$ (K)
$\text{LaO}_{0.89}\text{F}_{0.11}\text{FeAs}$	26[11]
$\text{LaO}_{0.9}\text{F}_{0.2}\text{FeAs}$	28.5[12]
$\text{CeFeAsO}_{0.84}\text{F}_{0.16}$	41[11]
$\text{SmFeAsO}_{0.9}\text{F}_{0.1}$	43[11][13]
$\text{La}_{0.5}\text{Y}_{0.5}\text{FeAsO}_{0.6}$	43.1[14]
$\text{NdFeAsO}_{0.89}\text{F}_{0.11}$	52[11]
$\text{PrFeAsO}_{0.89}\text{F}_{0.11}$	52[15]
$\text{ErFeAsO}_{1-y}$	45[16]

# Сверхпроводимость почти без электронов

## Evidence for bulk superconductivity in pure bismuth single crystals at ambient pressure

Prakash *et al.*, *Science* **355**, 52–55 (2017) 6 January 2017

$$n \approx 3 \times 10^{17} \text{ cm}^{-3}$$



Single gap superconductivity in doped  $\text{SrTiO}_3$

<https://arxiv.org/abs/1703.04716>

Плотность носителей  $10^{18} - 10^{20}$

$\epsilon > 20\,000$

Слабо допированный почти сегнетоэлектрик



# 2D superconductors

Supercond. Sci. Technol. 30 (2017) 013002 (37pp)

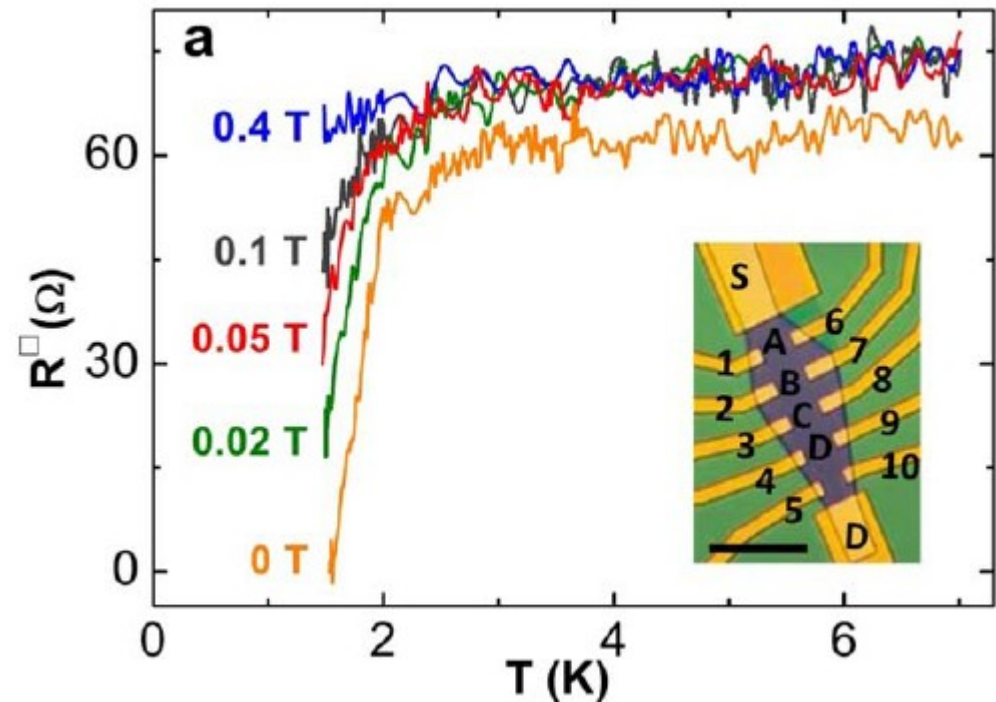
Takashi Uchihashi

## Two-dimensional superconductors with atomic-scale thickness

$\text{LaAlO}_3/\text{SrTiO}_3$

Atomic-thickness interface between two insulators

$\text{MoS}_2$  – атомный слой



# Очень сильно неупорядоченные сверхпроводники и квантовый переход сверхпроводник-изолятор

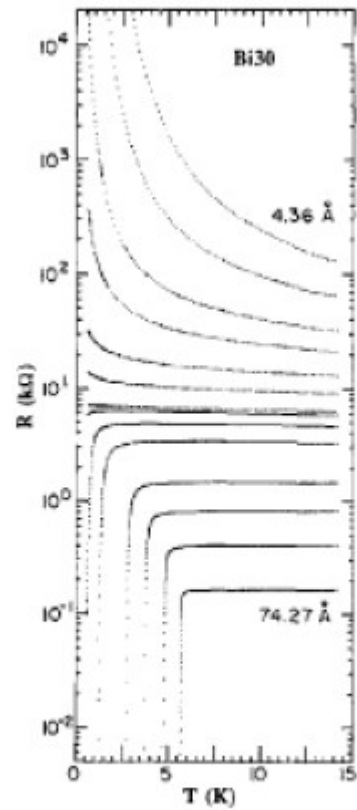
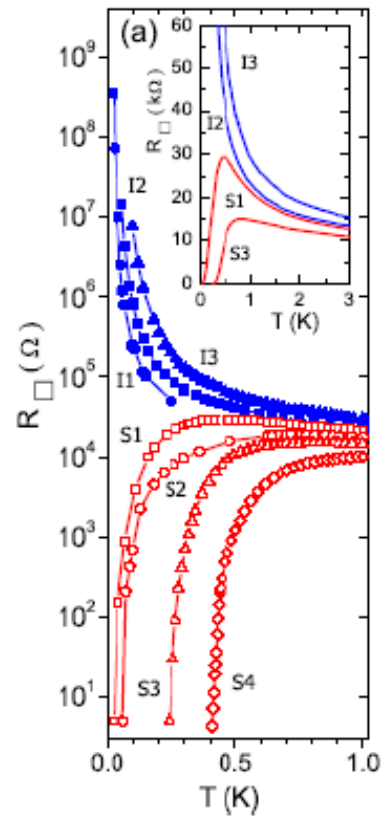


Fig. 5. Temperature dependence of the sheet resistance  $R(T)$  for Bi films deposited onto Ge [15]. The films are considered to be homogeneous.



TiN thin films

Nearly critical InOx :

B.Sacepe M.Ovadia  
D.Shahar (2009)

