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SEARCH FOR HIGHER CRITICAL TEMPERATURE (T_C) IN SUPERCONDUCTING MATERIALS

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ABSTRACT

Superconductivity occurs in several materials like elements, alloys, ceramics, organic, heavy fermions, borocarbides, heavily doped semiconductors, iron and hydrogen based materials. Niobium has the highest transition temperature (T_c) ≈ 9.3K, among metals. Until 1986, the highest T_c was 23.2 K achieved in Nb_3Ge. The highest T_c (135K) was found in cuprate superconductor of HgBaCaCuO system. For Hg 1223 T_c onset was found to be 157K at 23.5 Gpa and an onset of 164K at 35 Gpa. The highest-T_c in iron based superconductors is 56 K. The superconductivity at 39 K in magnesium diboride offers the possibility of a new class of superconducting materials. $CeCoIn_5$ exhibits the highest critical temperature (T_c= 2.3 K) of the heavy fermion superconductors. The highest critical temperature obtained for an organic superconductor is 117 K which was found for hole doped C_{60} intercalated with $CHBr_3$. Recently hydrogen sulfide (H_2S) under extremely high pressure (≈150 gigapascals) was found to undergo superconducting transition near 203 K (-70 °C), the highest temperature superconductor known to date. In this paper the overview of materials that exhibit superconductivity with their critical temperature (T_c) are presented.

Keywords: niobium, cuprate superconductors, organic superconductor, hydrogen sulphide.

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I INTRODUCTION

Dutch scientist Heike Kammerlingh Onnes [1] first discovered the phenomenon of superconductivity in 1911. He found that below 4.5 K the dc resistance of mercury dropped to zero. Ones found similar transitions in lead and tin. The characteristic temperature at which there is complete disappearance of electrical resistance is called transition or critical temperature (T_c). The value of critical temperature (T_c) varies from material to materials The actual critical temperature of a material is dependent on the purity of the material, the crystal orientation and whether it is a single crystal or polycrystalline sample.

Superconductivity can be destroyed by the application of magnetic field larger than a thermodynamic critical magnetic field (H_c). Also, when the current density in a superconductor exceeds the critical current density J_c, superconductivity is destroyed. In 1933, Meissner and Oschenfeld [2] observed that when a material is cooled in the presence of a magnetic field, on reaching its superconducting transition temperature (T_c) the magnetic flux is suddenly completely expelled from its interior. It means it exhibits perfect diamagnetism. Thus, it was established that perfect diamagnetism, in addition to zero resistivity, is a fundamental property of the superconducting state.

II ELEMENTAL SUPERCONDUCTORS

Basic conductive elements are type I superconductors having low critical temperature (T_c). Among the elements niobium was found to have the highest transition temperature (9.3K). Table 1 show the critical temperature of superconducting elements.

Element	**Symbol**	**T_c(K)**
Beryllium	Be	0.026
Aluminum	Al	1.2
Titanium	Ti	0.4
Vanadium	V	5.4
Zinc	Zn	0.85
Gallium	Ga	1.1
Zirconium	Zr	0.8
Niobium	Nb	9.25
Molybdenum	Mo	0.92
Technetium	Tc	8.2
Ruthenium	Ru	0.5
Rhodium	Rh	0.5
Cadmium	Cd	0.52
Indium	In	3.4
Tin	Sn	3.72
Hafnium	Hf	0.16

Tantalum	Ta	4.4
Tungsten	W	0.01
Rhenium	Re	1.7
Osmium	Os	0.7
Iridium	Ir	0.1
Mercury	Hg	4.15
Thallium	Tl	2.4
Lead	Pb	7.2
Lanthanum	La	6
Thorium	Th	1.4
Protactinium	Pa	1.4
Uranium	U	0.7
Americium	Am	1
Lutetium	Lu	0.1

Table 1 Critical temperature of superconducting elements.

III ELEMENTAL SUPERCONDUCTORS ONLY UNDER PRESSURE

Some elemental type I superconductors require high pressure to reach superconductivity, which are shown in table 2.

Element	**Symbol**	**T_c**	**P(Gpa)**
Lithium	Li	7	26
Boron	B	11.2	250
Oxygen	O	0.6	120
Calcium	Ca	15	150
Scandium	Sc	0.3	21
Iron	Fe	2	21
Silicon	Si	8.5	12
Phosphorus	P	5.8	17
Sulphur	S	17	160
Germanium	Ge	5.4	11.5
Arsenic	As	2.7	24
Selenium	Se	7	13
Bromine	Br	1.4	150
Antimony	Sb	3.6	8.5
Tellurium	Te	7.4	35
Iodine	I	1.2	2.5
Bismuth	Bi	8.7	9
Strontium	Sr	4	50
Yttrium	Y	2.8	15
Cesium	Cs	1.5	5
Barium	Ba	5	15

Table 2 Elemental Superconductors only under pressure

IV ALLOYS SUPERCONDUCTORS

It was found that when alloying a non superconducting metal with a superconducting one T_c may be increased. Low temperature superconductors were elemental metals and metallic alloys, while most pure elemental; materials like tin, aluminium were called as type I superconductors. Metallic alloys like niobium nitride, niobium titanium and niobium germanium alloys were classified as type II superconductors. However, most of these are superconducting below 30K. Until 1986, the highest T_c was 23.2 K [3] achieved in 1973 for niobium-germanium thin films with stoichiometric composition Nb_3Ge.

S.N.	Materials	T_c (K)	S.N.	Materials	T_c (K)
1	NbTi	10	16.	MoC	7.7
2.	PbMoS	14.4	17.	MoN	12
3	V_3Ga	16.5	18	PbS	4.1
4.	NbN	15.7	19.	NbC	10.1
5.	V_3Si	16.9	20.	TaC	9.2
6.	Nb_3Sn	18	21.	CuS	1.6
7.	Nb_3Al	18.7	22.	VN	1.3
8.	$Nb_3(AlGe)$	20.7	23.	WC	2.8
9.	Nb_3Ge	23.2	24.	W_2C	2.05
10.	Nb_3Au	11.5	25.	Nb_3Ga	21
11.	Bi_6Tl_3	6.5	26.	TiN	1.4
12.	Sb_6Tl_7	5.5	27.	TiC	1.1
13.	Na_2Pb_5	7.2	28.	NbC	10.1
14.	Hg_5Tl_7	3.8	29.	ZrB	2.82
15.	Au_2Bi	1.84	30	TaSi	4.2

Table 3 Alloys superconductors with their critical temperature.

V OXIDE SUPERCONDUCTORS

The first known metallic oxide was $SrTiO_3$ with $T_c \approx 0.3$ K [4], which could be raised to 1.2K by alloying with niobium. A T_c of 13K was discovered in Li-Ti oxide system ($LiTi_2O_4$) [5, 6], in which spinel phase was responsible for superconductivity. Of greater significance was the discovery of superconductivity in the material $BaPb_{1-x}Bi_xO_3$ at 13K by Sleight et al [7], which crystallizes in the perovskite structure. In September 1986, J.G. Bednorz and K.A. Muller [8] of IBM Zurich Research Laboratory, Switzerland, found T_c near 30K in barium substituted $LaCuO_4$. The phase responsible for superconductivity was identified to have nominal composition $La_{2-x}Ba_xCuO_{4-y}$ (x=0.2) having K_2NiF_4 structure. Later on, it was confirmed by various groups [9-14] that replacement of Ba by Sr enhances T_c to 57 K by application of pressure. This discovery opened the way for all the subsequent work on high T_c superconductors. In 1987, Chu et al [15] at Houston synthesized the compound $YBa_2Cu_3O_{7-x}$ with a T_c few degrees above 90K. H. Maeda et al. [16] in 1988 first report the existence of a superconducting phase with a T_c of around 105K in BiSrCaCuO at the Tsukaba laboratories in Japan. It was quickly established that a new series of superconductors had the structural formula type $Bi_2Ca_{n-1}Cu_nO_{2n-4}$ with T_c of 10, 85 and 110K for n = 1, 2 and 3 respectively [17-25]. Shortly afterwards, Z.Z. Sheng and A.M. Hermann [26] announced superconductivity above 100K in the TlBaCaCuO system.

Again several groups established the structural formula for this system as $Tl_2Ba_2Ca_{n-1}Cu_nO_{2n+4}$ with T_c of 80, 110 and 125 K for n=1,2 and 3 respectively [27-30]. In 1993, Putilin et al. [31] and Shilling et al. [32] announced the discovery of superconductivity in HgBaCaCuO system with three CuO_2 layers per unit cell in $HgBa_2Ca_2Cu_3O_{1+x}$ and two CuO_2 layers per unit cell in $HgBa_2CaCu_2O_{6+x}$ compound, the highest known T_c, over 135K. At 23.5 Gpa T_c onset for Hg 1223 was found to be 157K [33,34] and an onset of 164K at 35 Gpa [35]. The key features, which govern the T_c of this compound, are the number of CuO layers in a unit cell.

S.N.	**Materials**	**Tc (K)**
1	$La_{1.85}Ba_{0.15}CuO_4$	40
2.	$YBa_2Cu_3O_7$	92
3	$Bi_2Sr_2CuO_6$	20
4.	$Bi_2Sr_2CaCu_2O_8$	85
5.	$Bi_2Sr_2Ca_2Cu_3O_{10}$	110
6.	$Tl_2Ba_2CuO_6$	80
7.	$Tl_2Ba_2CaCu_2O_8$	108
8.	$Tl_2Ba_2Ca_2Cu_3O_{10}$	125
9.	$TlBa_2Ca_3Cu_4O_{11}$	122
10	$HgBa_2CuO_4$	94
11	$HgBa_2CaCu_2O_6$	128
12	$HgBa_2Ca_2Cu_3O_8$	134

Table 4 Oxide superconductors with their critical temperature

VI IRON BASED SUPERCONDUCTORS

Iron based superconductors have the highest superconducting transition temperature next to copper oxide. The highest-T_c in iron based superconductors is 56 K. Iron based superconductor was first discovered in LaFePO [36] with T_c ~4 K. Subsequently superconductivity was found in LaNiAsO [37] with $T_c = 2.4$ K and then T_c jumped to 26 K for $LaFeAsO_{1-x}F_x$ by replacing phosphorus with arsenic and some of the O atoms replaced by F atoms [38]. An increased T_c of 56 K in $SmO_{1-x}F_xFeAs$ [39] and $Gd_{1-x}Th_xFeAsO$ [40] was reported. Iron based superconductors have been extended to a large variety of materials including four prototypical families of iron based superconductors 1111,122,111, and 11 types and further variations such as 42622 and 32522 type iron pnictides [41] and 122 type iron chacogenides[42]

The first high-T_c iron based superconductor was discovered by a partial replacement of F^- ion at the oxygen site in La-1111 compounds. The 1111 type compounds have a 2-dimensional electronic structure and a metallic conducting FeAs layer are sandwiched by insulating and LaO layers. The 1111 family includes LaFePO and $LaFeAsO_{1-x}F_x$ and LnFeAsO with various lanthanide elements (Ln). The electrical resistivity of pure LaFePO drops at 4K and that of F-doped LaFePO drops at higher temperature (~10K). With doping of F replacing O in part, $LaFeAsO_{0.89}F_{0.11}$ becomes superconducting. When small pressure is applied to $LaFeAsO_{0.89}F_{0.11}$, T_c increases, reaching maximum value of T_c =43K at 4 GPa and then it decreases to T_c=9K at 30GPa. Electron doping into RE-1111 compounds (where RE = rare earth metal) was very successful, i.e., the max. T_c was increased from 26 K to 55 K by replacing La with other RE ion with smaller ionic radius. The value of T_c (K) in 1111-type materials are shown in table 5

System	Parent compound	T_c (K)	P (GPa)
1111	CaFeAsF	29	5
	CaFeAsH	28	3.3
	$Ca(Fe_{1-x}Co_x)AsF$	24.7	1
	SrFeAsF	25	16.5
	$LaFeAsO_{0.89}F_{0.11}$	43	3
	LaFeAsO	21	12
	LaFePO	4	-
	$LaFeAsO_{0.65}H_{0.35}$	46	3
	$LaFeAsO_{0.89}F_{0.11}$	9	30
	$LaFeAsO_{0.89}F_{0.11}$	26	-
	SmFeAsO	11	9
	$SmFeAsO_{0.9}F_{0.1}$	55	-
	$SmFeAsO_{0.85}$	41	7
	$CeFeAsO_{0.84}F_{0.16}$	41	-
	$CeFeAsO_{0.88}F_{0.12}$	1.1	26.5
	$NdFeAsO_{0.85}$	35	7
	$NdFeAsO_{1-y}$	54.3	-
	$PrFeAsO_{0.89}F_{0.11}$	52	-
	$GdFeAsO_{1-y}$	54	-
	$Gd_{1-x}Th_xFeAsO$	56	-

Table 5 T_c in 1111 type iron based superconductors along with the doping modes and pressure dependence.

The 122- and 111- type families have simpler structures than the1111 type family. $BaFe_2As_2$ is a member of the 122 iron-pnictides family [43]; each unit cell contains two FeAs trilayer separated by a layer of barium ions. In this class of materials, superconductivity arises following chemical substitution into the undoped compound as in the case of Ni_x substitution into $BaFe_2As_2$.In FeAs-122, the highest T_c~49K can be achieved in Pr-doped $CaFe_2As_2$ [44] The values of T_c in 11,111 and 122 type iron based superconducting material are shown in table 6.

System	Parent compound	T_c (K)	P (GPa)
11 or 111	FeSe	8	-
	FeSe	36.7	8.9
	$FeTe_{0.5}Se_{0.5}$	14	-
	$Fe_{1.01}Se$	36.7	8.9
	$Fe_{1.13}Te_{0.85}Se_{0.1}$	2	-
	$FeTe_{0.8}Se_{0.2}$	10	-
	NaFeAs	33	4
	$NaFe_{0.972}Co_{0.028}As$	31	2.28
	LiFeAs	7	8
122	$CaFe_2As_2$	12	0.5
	$Ca_{0.6}Na_{0.4}Fe_2As_2$	21	-
	$SrFe_2As_2$	40	2.5
	$Sr_{0.6}Na_{0.4}Fe_2As_2$	26	-

	$BaFe_2As_2$	35	1.5
	$EuFe_2As_2$	41	10
	$Ba_{0.55}K_{0.45}Fe_2As_2$	27	20
	$Ba(Fe_{0.926}Co_{0.074})_2As_2$	10	5.5
	$BaFe(As_{0.65}P_{0.35})_2$	19	38
	$Ba_{0.87}La_{0.13}Fe_2As_2$	30	2.8
	$Ba_{0.6}La_{0.4}Fe_2As_2$	38	-

Table 6 T_c in 111 and 122 type iron based superconductors along with the doping modes and pressure dependence.

The 11-type materials are in iron chalcogenide which started with FeSe having T_c of 8K at ambient pressure [45] and 36.7K with applied pressure of 8.9 GPa. This family also includes Fe $Te_{1-x}Se_x$ and $FeTe_{1-x}S_x$. The highest critical temperatures in the iron-based superconductor family exist in thin films of FeSe[46,47,48]where a critical temperature in excess of 100 K has recently been reported.[49] The superconducting transition temperature of iron pnictides and chalcogenides are high compared to those of conventional superconductors

VII BORIDES AND BOROCARBIDE SUPERCONDUCTORS

Since 1994, there has been a renewed interest in intermetallic superconductors which incorporate light elements, such as boron , due to the discovery of the new class of borocarbides RE-TM_2B_2C, where RE= Y, Lu, Er, Dy or other rare earths and TM = Ni or Pd [50,51]

The main characteristics of these compounds are very high T_c among intermetallics (T_c=23 K in YPd_2B_2C), the anisotropic layered structure and a strong interplay between magnetism and superconductivity.

The discovery of superconductivity at 39 K in magnesium diboride [52] offers the possibility of a new class of superconducting materials. MgB_2 has an unusual high critical temperature of about 40 K among binary compounds with an AIB_2-type structure with graphite-type boron layers separated by hexagonal closed packed layers of Mg.Several other related materials are known to be superconductive, but MgB_2 holds the record of T_c in its class. The discovery of the superconductivity in MgB_2 revived the interest in non –oxides and initiated a search for superconductivity in related material. Table 7 show the binary, ternary and quaternary borides and borocarbides with their critical temperatures.

S.N.	**Compound**	**T_c(K)**	**S.N.**	**Compound**	**T_c(K)**	**S.N.**	**Compound**	**T_c(K)**
1	TaB	4	25	ScB_{12}	0.39	49	$SmRh_4B_4$	2.51
2	NbB	8.25	26	YB_{12}	4.7	50	$ErRh_4B_4$	8.55
3	ZrB	2.8-3.4	27	LuB_{12}	0.48	51	$TmRh_4B_4$	9.86
4	HfB	3.1	28	ZrB_{12}	5.82	52	$LuRh_4B_4$	11.7
5	MoB	0.5	29	$YRuB_2$	7.8	53	$ThRh_4B_4$	4.34
6	MgB_2	40	30	$LuRuB_2$	9.9	54	$DyRh_2Ir_2B_4$	4.64
7	NbB_2	0.62	31	$ScOsB_2$	1.34	55	$HoRh_2Ir_2B_4$	6.41
8	$NbB_{2.5}$	6.4	32	$YOsB_2$	2.22	56	$ErIr_4B_4$	2.34
9	$Nb_{0.95}Y_{0.05}B_{2.5}$	9.3	33	$LuOsB_2$	2.66	57	$TmIr_4B_4$	1.75
10	$Nb_{0.9}Th_{0.1}B_{2.5}$	7	34	Mo_2BC	7.5	58	$TmRh_4B_4$	5.4

11	$MoB_{2.5}$	8.1	35	$Mo_{1.18}Rh_{0.2}BC$	9	59	$ErRh_4B_4$	4.3
12	$Mo_{0.9}Sc_{0.1}B_{2.5}$	9	36	$Nb_2BN_{0.98}$	2.5	60	$LuRh_4B_4$	6.2
13	$Mo_{0.95}Y_{0.05}B_{2.5}$	8.6	37	YB_2C_2	3.6	61	$Sc\ Rh_4B_4$	7.23
14	$Mo_{0.85}Zr_{0.15}B_{2.5}$	11.2	38	LuB_2C_2	2.4	62	$Lu\ Rh_4B_4$	2.06
15	$Mo_{0.85}Nb_{0.15}B_{2.5}$	8.5	39	$Ca_{0.67}Pt_3B_2$	1.57	63	$Er\ Rh_4B_4$	7.8
16	TaB_2	9.5	40	$Sr_{0.67}Pt_3B_2$	2.78	64	YRu_2B_2C	9.7
17	Mo_2B	5.07	41	$Ba_{0.67}Pt_3B_2$	5.6	65	$DyNi_2B_2C$	6.2
18	W_2B	3.22	42	$LaRh_3B_2$	2.82	66	$HoNi_2B_2C$	8.7
19	Re_3B	4.7	43	$LaIr_3B_2$	1.65	67	$ErNi_2B_2C$	10.5
20	Ru_7B_3	2.58	44	$LaOs_3B_2$	4.67	68	$LuNi_2B_2C$	16.1
21	YB_6	7.1	45	$ThRu_3B_2$	1.79	69	YPd_2B_2C	23
22	LaB_6	5.7	46	$LaIr_3B_2$	2.09	70	YPt_2B_2C	10
23	ThB_6	0.74	47	YRh_4B_4	11.3	71	$ThPd_2B_2C$	6.5
24	NdB_6	3	48	$NdRh_4B_4$	5.36	72	$PrPt_2B_2C$	6

Table 7. Borides and borocarbides with their critical temperatures.

VIII HEAVY FERMION SUPERCONDUCTORS

The heavy fermions materials are typically inter-metallic in which one of the constituents is a rare earth or actinide element having a partially filled 4f or 5f shell. Superconductivity exists in several uranium compounds namely UPt_3, UBe_{13}, URu_2Si_2, UPd_2Al_3, $UNi_2Al_{3,}$ and U_2PtC_2 with both a transition to an antiferromagnetically ordered state and then a transition to a superconducting state. Superconductivity in hexagonal UPt_3 with T^{+}_{c} = 0.53K has more than one superconducting phase below T_c. UPt_3 showed strongest evidence for the unconventional superconductivity in heavy fermions superconductors [53]. UBe_{13} is a non–Fermi Liquid superconductor [54] because the superconducting state appears (near T_c = 0.9 K) before Fermi liquid behavior has a chance to set in. Tetragonal URu_2Si_2 enters the superconducting state near 1.5K. The superconducting state of UPd_2Al_3 condenses near T_c ~2.0 K out of a coexisting antiferromagnetic state (T_N= 14.5 K) with atomic–like moments aligned in the hexagonal basal plane [55]. Superconductivity in UNi_2Al_3 appears near 1 K and coexists with an incommensurate spin density wave state with a relatively small magnetic moment that appears near 4.5 K [56]. $CeRhIn_5$ exhibit superconductivity over a wide pressure region from 1.6 to 5.2GPa. At P_c ~2.0 GPa, T_N thus touches the superconducting region. The specific heat measurements suggest that the antiferromagnetic state is abruptly replaced by a superconducting state with maximum T_c of 2.6 K around 2.3 – 2.5 GPa [57]. Just at the edge of an antiferromagnetic quantum critical point, tetragonal $CeCoIn_5$ exhibits the highest critical temperature (T_c = 2.3 K) of the heavy fermion superconductors [58]. Under ambient pressure $CeIn_3$ is a heavy fermion antiferromagnet with an ordering temperature T_N = 10.2 K. As pressure is applied T_N is depressed and eventually vanishes near a temperature of about 0.18 K at a critical pressure of about 26 kbar, below this temperature antiferromagnetism is replaced by a superconducting state. Recently Ce-based heavy-fermion system, namely $CePt_3Si$, was found showing antiferromagnetism and superconductivity (T_N=2.2 K and T_c=0.75 K) at ambient pressure. The compound $PrOs_4Sb_{12}$ [59]has a relatively low superconducting critical temperature (T_c) of 1.85K and a high-quality single crystal of PrV_2Al_{20} exhibits superconductivity at T_c=50 mK in the antiferroquadrupole-ordered state under ambient pressure[60]. Table 8 show critical temperature of heavy fermions superconductors

Materials	**T_c(K)**
$CeCu_2Si_2$	0.7
$CeCoIn_5$	2.3
$CePt_3Si$	0.75
$CeIn_3$	0.2
UBe_{13}	0.85
UPt_3	0.48
URe_2Si_2	1.3
UPd_2Al_3	2.0
UNi_2Al_3	1.1

Table 8. Critical temperature of heavy fermions superconductors

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IX ORGANIC SUPERCONDUCTORS

Several different types of organic superconductors have been identified such as the quasi-one-dimensional Bechgaard salts [61] and quasi-two-dimensional salts derived from the donor molecule [62]. More recently, superconductivity has been observed in fullerenes, [63-65] nanotubes, [66] acenes, [67] polythiophene, [68] and oligomers of poly-phenylene-vinylene [69]. Table 9 show the critical temperature of various organic superconductors.

S.N.	Organic superconductor	Critical temperature (T_c)
1.	C_{60}	38K at 0.7GPa
2.	Aromatic hydrocarbons	33K at ambient pressure
3.	$M(dmit)_2$	8.4K at 0.45GPa
4.	Graphite	15.1K at 7.5GPa
6.	Carbon nanotubes	15K in Zeolite
7.	B-doped diamond	11K at ambient pressure
8.	Single component organic compounds	< 2.3K at 58Gpa

Table 9. Various organic superconductors with their critical temperature

The first organic superconductors consisted of planar tetramethyltetraselenafulvalene (TMTSF) donors and monovalent anion acceptors with the general formula $(TMTSF)_2X$, where X is either an octahedral or tetrahedral anion such as PF_6-, AsF_6-, $SbPF_6$-, TaF_6-, NbF_6-, ClO_4-,or ReO_4-. The $(TMTSF)_2PF_6$ was synthesized with a transition temperature of T_c = 1.1 K, at an external pressure of 6.5 kbar. Only one Bechgaard-salt was found to be superconducting at ambient pressure which is $(TMTSF)_2ClO_4$ with a transition temperature of T_c = 1.4 K, while other salts become superconducting only under external pressure (5-12Kbar). Table 1 shows transition temperature of several one-dimensional organic superconductors.

One Dimensional Organic Superconductor	**T_c (K)**
$(TMTSF)_2SbF_6$	0.36
$(TMTSF)_2PF_6$	1.1
$(TMTSF)_2AsF_6$	1.1
$(TMTSF)_2ReO_4$	1.2
$(TMTSF)_2TaF_6$	1.35
$(TMTTF)_2Br$	0.8
$(TMTSF)_2ClO_4$	1.4

Table 10 Transition temperature of several one-dimensional organic superconductors

In quasi two dimensional superconductors a new donor BEDT-TTF [bis (ethylenedithio) tetrathiafulvalene [66], was synthesized which contains eight sulfur atoms. The external pressure needed to drive an BEDT-TTF-salt with insulating ground state to a superconducting one is much smaller than those needed for Bechgaard salts. For example κ-$(ET)_2Cu[N(CN)_2]Cl$ needs only a pressure of about 300 bar to become superconducting. The highest transition temperatures at ambient pressure and with external pressure are both found in κ-phases with very similar anions. κ-$(ET)_2Cu[N(CN)_2]Br$ becomes superconducting at T_c = 11.8 K at ambient pressure, and a pressure of 300 bar drives deuterated κ-$(ET)_2Cu[N(CN)_2]Cl$ from an antiferromagnetic to a superconducting ground state with a transition temperature of T_C = 13.1 K.Table 11 shows quasi two dimensional organic superconductors with T_c (K).

Material	**T_c (K)**
β_H-(ET)$_2$I$_3$	1.5
θ-(ET)$_2$I$_3$	3.6
k-(ET)$_2$I$_3$	3.6
α-(ET)$_2$KHg(SCN)$_4$	0.3
α-(ET)$_2$KHg(SCN)$_4$	1.2
β''-(ET)$_2$SF$_5$CH$_2$CF$_2$SO$_3$	5.3
κ-(ET)$_2$Cu[N(CN)$_2$]Cl	12.8
κ-(ET)$_2$Cu[N(CN)$_2$]Cl deuterated	13.1
κ-(ET)$_2$Cu[N(CN)$_2$]Br deuterated	11.2
κ-(ET)$_2$Cu(NCS)$_2$	10.4
κ-(ET)$_4$Hg$_{2.89}$Cl$_8$	1.8
κ_H-(ET)$_2$Cu(CF$_3$)$_4$·TCE	9.2

Table 11.Quasi two dimensional organic superconductors with T_c(K)

Complexes such as β-(BEDT-TTF)$_2$X where X is I$_3$- , Br-I-Br- , and I-Au-I- have all shown superconductivity with critical temperatures of 1.5, 2.7, and 4.9 K, respectively. Unfortunately, no further advancements have been made in the search for a higher critical temperature for quasi two dimensional organic superconductors [70].

Fullerene is a three dimensional insulator with a band gap of 1.7 eV, but on doping with alkali metals[71] produces superconductivity with critical temperatures up to 40 K. General formula for these superconductors is A_3C_{60} where A is an alkali metal. The highest measured transition temperature up to 1995 for an organic superconductor in Cs_3C_{60} pressurized with 15 kbar to be $T_c = 40$ K [72].

Hole doped fullerenes exhibit higher critical temperature than electron doped fullerenes. Recently, a hole-doped C_{60} superconducting system $C_{60}/CHBr_3$, which exhibited very high critical temperature $T_c = 117$K at ambient pressure, is the highest T_c for an organic superconductor achieved with a buckyball doped with holes and intercalated with $CHBr_3$[64]. It has been predicted that by hole doped and intercalated method very high T_c superconductor up to 150K can be developed. Table 12 shows various fullerene derivative superconductors with their critical temperature

Organic superconductors	**T_c (K)**
K_3C_{60}	18
Rb_3C_{60}	30.7
K_2CsC_{60}	24
K_2RbC_{60}	21.5
K_5C_{60}	8.4
Sr_6C_{60}	6.8
$(NH_3)_4Na_2CsC_{60}$	29.6
$(NH_3)K_3C_{60}$	28
$RbCs_2C_{60}$	33
Cs_3C_{60}	40
$C_{60}/CHBr_3$	117

Table 12 Various fullerene derivative superconductors with their critical temperature

The superconductivity has been observed for many M_3C_{60} (M: alkali metal), e.g., Rb_3C_{60} (T_c = 29 K [73]), Rb_2CsC_{60} (T_c = 31 K [74]), and $RbCs_2C_{60}$ (T_c = 33 K) [75].

In polyaromatic hydrocarbon superconductors the bulk superconducting phase was observed below 7 K and 18 K for K_3 picene, and 7 K for Rb_3 picene, which are comparable to that of K_3C_{60} (T_c = 19 K). After the discovery of the picene-based superconductors, several superconductors have been found for alkali metal (T_c = 7 K) [76] and alkaline-earth metal (T_c ~ 5.5 K) [77] doped phenanthrene, potassium-doped 1, 2:8, 9-dibenzopentacene (T_c = 33 K; partially decomposed) [78], and potassium-doped coronene (T_c < 15 K) [79]. Among them, a phenanthrene-based superconductor shows an enhancement of T_c with increasing pressure, which is indicative of the non-BCS behavior. So far 8 aromatic hydrocarbon superconductors were prepared with the highest T_c of 33 K at ambient pressure.

The first superconducting carbon nanotubes were discovered for ropes of single walled carbon nanotubes with diameters of the order of 1.4 nm (T_c = 0.4 K) [80], and immediately after that a single walled nanotubes with diameters of 0.4 nm embedded in a zeolite matrix (T_c = 15 K) [81, 82].

Multi-walled carbon nanotubes with diameters of 10–17 nm that were grown in nanopores of alumina templates was found to show superconductivity with T_c = 12 K [83].

First-stage alkali metal doped graphite intercalation compound were known to superconduct with T_c = 0.15 K for KC_8 [84]. Further efforts were poured to synthesize graphite intercalation compound with higher T_c , such as LiC_2 with T_c = 1.9 K [85]. In 2005, these efforts culminated in the discovery of CaC_6 with T_c as high as 11.5 K at ambient pressure [86], which goes up to 15.1 K under pressures up to 7.5 GPa [87]. In other alkaline-earth metal doped graphite intercalation compounds, the superconducting phase was observed below 1.65 K for SrC_6 and 6.5 K for YbC_6 [88].

Superconductivity in diamond was achieved through heavy p-type doping by boron with critical temperature T_c = 4 K and critical magnetic field H_c =4T, which was performed under high pressure (8–9 GPa) and high temperatures (2500–2800 K) [89]. There are two single-component superconductors under extremely high pressure, p-iodanil (T_c ~ 2 K at 52 GPa) and hexaiodobenzene (T_c = 0.6–0.7 K at around 33 GPa and 2.3 K at 58 GPa).

X HYDROGEN BASED SUPERCONDUCTOR

Hydrogen sulfide (H_2S) under extremely high pressure (around 150 gigapascals) was found to undergo superconducting transition near 203 K (-70°C), the highest temperature superconductor known to date [90]. It has been predicted that by substituting a small part of sulfur with phosphorus and using even higher pressures it may be possible to raise the critical temperature to above 0°C (273 K) and achieve room-temperature superconductivity [91].

Material	**T_c(K)**	**P (Gpa)**
Hydrogen sulfide (H_2S)	203	150

Table 13 Critical temperature of hydrogen based superconductors

XI CONCLUSION

The highest accepted superconducting critical temperature (T_c) till date is 203K in highly pressurized hydrogen sulphide. Previously the cuprate shows superconductivity as high as 138K at atmospheric pressure and 164K under high pressure. Researchers are attempting to find superconductivity at increasing temperature with the goal of finding room temperature superconductor that would help to solve energy problems, provide faster computers, allow for novel memory storage devices and enable ultrasensitive sensors etc.

References

[1] H. K. Onnes, Leiden Commun., **122b, 124C** (1911)
[2] W. Meissner and R. Oschenfeld, Naturwiss, **21** 787(1933)
[3] J. R. Gavaler, Appl. Phys. Lett. **23** 480 (1973)
[4] G. Binnig, A. Baratoff, H. E. Hsenig, J. G. Bednorz, Phys. Rev. Lett., 1352(1980)
[5] D. C. Johnston, J. Low Temp. Phys., **25,** 145(1976)
[6] D. C. Johnston, H. Prakash, et.al. Mater. Res. Bull., **8**, 777(1973)
[7] A. W. Sleight, J. L. Gillson and F. E. Bierstedt, Solid state Commun. **17,** 27(1975)
[8] J. G. Bednorz and K. A. Muller, Z Phys. B, **64,** 189(1986)
[9] R. J. Cava, R. B. VanDover, et.al. Phys. Rev. Lett. **58**, 408(1987)
[10] J. M. Tarescon, L. H. Greene, et.al. Science, **235,** 1373(1987)
[11] J. G. Bednorz, K. A.Muller and M. Takashige, Science, **236,** 73(1987)
[12] R. B. Vandover, R. J. Cava, B. Batlog and E. A. Rietman, Phys. Rev. B, **35,** 53337(1987)
[13] D. U. Gubsev, R. A. Hein, S. H. Lawrence,et.al., Phys. Rev. B., **35,** 5350(1987)
[14] C. W. Chu, P. H. Hor, R. L. Meng, L. GaO and Z. J. Huang, Science **235,** 567(1987)
[15] M. K. Wu, J. R. Ashborn, C. J. Torng,et.al., Phys. Rev. Lett., **58,** 908(1987)
[16] H. Maeda, Y. Tanaka, M. Fukotomi and T. Asano, Jpn. J. Appl. Phys. **27,** L 207(1988)
[17] R. M. Hazen, C. T. Prewitt, R. J. Angel, et.al., Phys. Rev. Lett., **60,** 1174(1988)
[18] S. A. Sunshsine, T. Siegriest, L. F. Schneemeyer, et.al., Phys. Rev. B., **38,** 893(1988)
[19] J.M. Tarasen, P. Barboux, et.al. Physica C, **153-155,** 566(1988)
[20] P. Bordeet, J. J. Capponi, C. Chaillout,et.al., Physica C, **153-155,** 623(1988)
[21] M. A. Subramanium, C. C. Torardi, et.al. Science **239,** 1015(1988)
[22] J. L. Tallon, R. G. Buckley, et.al. Nature **333,** 6169(1988)
[23] H. W. Zandbergan, P. Groen, et.al. Solid State Communication **66,** 397(1988)
[24] J. M. Tarsen, Y. Le Page, P. Barboux,et.al., Phys Rev. B, **37,** 9382(1988)
[25] B. Revean, C. Michel, M. Hervieen and J Provost, Physica C, **153-155,** 3(1988)
[26] Z. Z.Sheng and H. M. Hermann, Nature, **332,** 55(1988)
[27] Z. Z. Sheng and H..M. Hermann, Nature, **332,** 138(1988)
[28] A. S. Alexandrov, P.P. Edwards, Physica C, **331,** 97 (2000)
[29] R. M. Hazen, L. W. Finger, et.al. Phys. Rev. Lett., **60,** 1657(1988)
[30] S. S. P. Parkin, V. Y. Lee, E. M. Engler, et.al. Phys. Rev. Lett., **60,** 2539(1988)
[31] S. N. Putilin, E. V. Antipov, O. Chmaissem and M.Marizio, Nature, **362,** 226(1993)
[32] A. Shilling, M. Cantoni, J. D. Gao and H. R. Ott, Nature **363,** 56(1993)
[33] C. W. Chu, L. Gao, Z. Chen, Z. J. Huang, R. l. Meng, Y. Y. Xue, Nature, **365,** 323(1993)
[34] M. Nuaez-Regueiro, et.al. Science, 262**,** 97(1993)
[35] L. Gao, Y.Y. Xue, F. Chen, et.al., Phys Rev. B. **50,** 4260(1994)

[36] Y. Kamihara et.al. , J. Am. Chem. Soc. **128**, 10012, (2006)

[37] T. Watanabe, H. Yanagi, et.al. Inorg. Chem., **46**, 7719(2007)

[38] Y. Kamihara, T. Watanabe, et.al. J. Am. Chem. Soc., **130**, 3296(2008)

[39] Z.A. Ren, et al. Chin. Phys. Lett., **25**, 2215(2008)

[40] C. Wang, et.al. Europhys. Lett. **83**, 67006(2008)

[41] H.Ogino et.al. Supercond. Sci. technol. **22,** 075008(2009)

[42] A.F. Wang et.al. Phys. Rev. B. **83**,060512 (R) (2011)

[43] D.C. Johnston, Adv. Phys., **59**, 1063(2010)

[44] B. Lv, L Z Deng and Gooch et.al. Proc. Natl. Acad. Sci., **108**, 15705(2011)

[45] F.C. Hsu et.al. Proc. Natl, Acad. Sci. U.S.A. **105**, 14262-264

[46] Wang, Qing-Yan; Li, Zhi; Zhang, et.al. Chin. Phys. Lett. **29** (3): 037402(2012)

[47] Liu, Defa; Zhang, Wenhao; Mou, Daixiang; et.al. Nat. Comms. **3,** 931(2012)

[48] He, Shaolong; He, Junfeng; Zhang, Wenhao; et.al. Nat. Mat. 12 (7): 605–610(2013)

[49] Jian-Feng Ge; et al. Nature Materials. 1406: 3435(2014)

[50] Nagarajan R, Mazumdar C, Hossain Z, et.al., Phys. Rev. Lett. **72**,274(1994)

[51] Cava. R. et.al. Nature, **367**,252(1994)

[52] Nagamatsu,Jun; Nakagawa, Norimasa; et.al., nature,**410,**6824, Jun (2001)

[53] H.R. Ott, H. Rudigier, Z. Fisk, and J. L. Smith, Phys. Rev. B, **31**, 1651 (1985)

[54] N. Oeschler, et.al, Acta Phys. Pol. B, **34** 255(2003)

[55] L. Paolasini, et.al. J. Phys. Cond. Mat., **5**, 8905(1993)

[56] A. Schr¨oder, et.al. Phys. Rev. Lett., **72**, 136(1994)

[57] H.Hegger et.al. Phys. Rev. Lett. **84**, 4986(2000)

[58] Petrovic,C;Pagliuso, P.G.; et.al. Journal of Physics Condense Matter 13, L337 (2001)

[59] R. Vollmer,et.al., Phys. Rev. Lett., 90, 057001/1(2003).

[60] Masaki Tsujimoto, et.al. Phys. Rev. Lett. **113,** 267001, 23 December (2014)

[61] (a) Bechagaard, K.et.al., Solid State Commun., **33**, 1119-1125(1980) (b) Bechgaard, K.et.al. ; J. Am. Chem. Soc. 103, 2440-2442(1981)

[62] Williams, J. M.et.al; Inorg. Chem., **29**, 3262-3265(1990)

[63] Dahlke, P.et.al; J. Am. Chem. Soc., **122**, 12352-12361(2000)

[64] Schon, J. H.; Kloc, Ch.; Batlogg, B. Science, **293**, 2432-2434(2001)

[65] Schon, J. H.; Kloc, Ch et.al. Nature, **413**, 831- 833(2000)

[66] Tang, Z. K.; Zhang, L.; Wang, N.et.al. Science, **292**, 7, 2462-2464. (2001)

[67] Schon, J. H.; Kloc, Ch.; Batlogg, B. Nature, **406**, 702-704(2000)

[68] (a) Jerome, D.; Bechgaard, K. Nature, **410**, 162-163(2001)

[69] Schon, J. H.; Kloc, Ch.; Wildeman, J.; Hadziioannou, G. Adv. Mat., **13,** 1273- 1274(2001)

[70] Ishiguro,T;Yamaji,K;Saito,G; Organic superconductors, Springer, Newyork, (1998)

[71] Shukur Majid M.,et.al.; Res. J. Chem. Sci., **2**(2), 28-34 (2012)

[72] Ganin, A. Y.; Takabayashi, Y; Khimyak, Y. Z.;et.al Nature Materials. **7** (5): 367–71(2008)

[73] Rosseinsky M J, et.al.; Phys. Rev. Lett. 66: 2830- 2832(1991)

[74] Tanigaki K, Ebbesen T W,et.al.; Nature **352**: 222-223(1991)

[75] Fleming R M, Ramirez A P,et.al. Nature **352**: 787-788.; (1991)
[76] Wang X F, Liu R H,et.al.; Nat. Commun. **2**: 507-513 (2011)
[77] Wang X F, et.al. Phys. Rev. B, **84**: 214523/1-4(2011)
[78] Xue M, Cao T, Wang D, Wu Y,et.al. Sci. Rep. **2**: 389/1–4(2012)
[79] Roth, F;J Bauer;Mahns.B; Buchner.B;Knupfer.M; Phys. Rev. B,**85**,014513,1, (2012)
[80] Kociak M, Kasumov A Yu, et.al. Phys. Rev. Lett. **86**, 2416-2419(2001)
[81] Tang Z K, Zhang L,et.al.; Science **292**, 2462-2465 (2001)
[82] Lortz R, Zhang Q, et.al. Proc. Natl. Acad. Sci. USA **106**, 7299-7303(2009)
[83] Takesue I, Haruyama J,et.al.; Phys. Rev. Lett. **96**: 057001/1-4(2006)
[84] Hannay N B, Geballe T H, et.al. Phys. Rev. Lett. **14**: 225-226(1965)
[85] Belash I T,et.al.; Solid State Commun. **69**: 921-923(1989)
[86] Weller T E, Ellerby M, Saxena S S, Smith R P, Skipper N T Nat. Phys. 1: 39-41(2005)
[87] Gauzzi A, Takashima S, et.al. ; Phys. Rev. Lett. **98**: 067002/1-4(2007)
[88] Kim J S, Boeri L, O'Brien J R,et.al. Phys. Rev. Lett. **99:** 027001/1-4(2007)
[89] Ekimov E A, Sidorov V, A,et.al.; Nature **428**: 542-545(2004)
[90] Drozdov, A. P.; Eremets, M. I.;et.al. Nature. **525**: 73–6(2015)
[91] Ge, Y. F.; Zhang, F.; Yao, Y. G. Phys. Rev. B. **93** (22): 224513(2016)