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## Enhancement of Superconductivity through Lattice Softening

**Abstract.** *The superconducting transition temperature of an iridium-yttrium eutectic is enhanced extraordinarily through lattice softening. This is shown by a drastically reduced Debye temperature.*

Iridium is a superconductor at 0.10 K (1). The eutectic formed by iridium with neighboring phases such as  $\text{YIr}_2$  or  $\text{EuIr}_2$  is a bulk superconductor with superconducting transition temperatures ( $T_c$ ) ranging from 2.7 to 3.7 K. Neither  $\text{YIr}_2$  nor  $\text{EuIr}_2$  by itself is superconducting above 1 K. The  $T_c$  of  $\text{EuIr}_2$  was found at 0.2 K (2), and that of  $\text{YIr}_2$ , apart from superconducting traces, is probably not above 20 mK (3). It has long been known that the addition of merely 1 atom percent yttrium will lead to inductive and resistive superconducting transitions above 3 K. However, this result had been considered due to the presence of a hypothetical second phase with the approximate composition  $\text{IrY} : 4\text{Ir}$ . Actually, yttrium and europium were not the only rare earth elements leading to a superconducting iridium eutectic; lanthanum and cerium had previously shown a similar behavior (4). We have now ascertained that the superconductivity observed is due to the eutectic proper and no other spurious or new phase is involved.

Measurements of the Debye temperature  $\theta_D$  show a spectacular drop from 420 K for pure iridium to 175 K near the eutectoid composition at about 22 atom percent Y. The system Ir-Y was chosen for the complete study because of the ab-

sence of significant second-phase formation for compositions as rich in Y as  $\text{Ir}_{0.9}\text{Y}_{0.1}$  as well as the absence of superconductivity of  $\text{YIr}_2$  above 20 mK. Previous results to the contrary must have been due to stoichiometric deficiencies (4). It is now apparent, and supported by metallography and transmission electron microscopy, that the enhanced bulk superconductivity of the eutectic is caused by the microscopic mixture of Ir with small amounts of  $\text{YIr}_2$ . This result is supported further by our specific heat measurements (Fig. 1), coupled with Debye-Scherrer x-ray powder patterns. Accordingly, these x-ray results indicate that  $\text{Ir}_{0.90}\text{Y}_{0.10}$  is at least 95 percent single-phase cubic Ir, with a lattice parameter of  $a_0 = 3.8389 \pm 0.0004 \text{ \AA}$ ;  $\text{Ir}_{0.99}\text{Y}_{0.01}$  has  $a_0 = 3.8395 \text{ \AA}$ , while pure Ir has  $a_0 = 3.8389 \text{ \AA}$ . This shows that far less

than 1 percent Y is soluble in Ir and that the excess Y does not enter the Ir lattice, since  $a_0$  is virtually unchanged, or form enough of a crystalline second phase to account for more than a small fraction of the Y present. The small amount of Y that dissolves in the Ir does not affect the  $T_c$  of the Ir. Inductive measurements show the Ir transition to remain at 0.10 K.

The specific heat measurements together with the x-ray results allow no other conclusion than that the microscopic mixture of Ir and  $\text{YIr}_2$  in the eutectic phase causes the eutectic to become a bulk conductor at 3.7 K, since the specific heat anomaly only near the eutectic composition indicates essentially a bulk effect. This microscopic mixture has such small grains of crystallinity that they are not seen in the x-ray patterns on unannealed, arc-melted samples. Furthermore, rapid quenching of the samples seems to adversely affect the superconductivity. Transmission electron microscopy reveals the classical picture of a lamellar eutectic (Fig. 2).

To shed some light on the phenomenon that the eutectic shows a superconducting transition enhanced by at least a factor of 30 over that of iridium, the element, it is of great interest to compare the specific heat measurements. In Fig. 1, lattice specific heat ( $\theta_D$ ) and electronic specific heat ( $\gamma$ ) are shown as

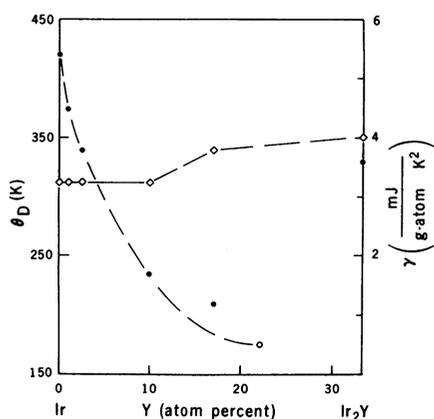
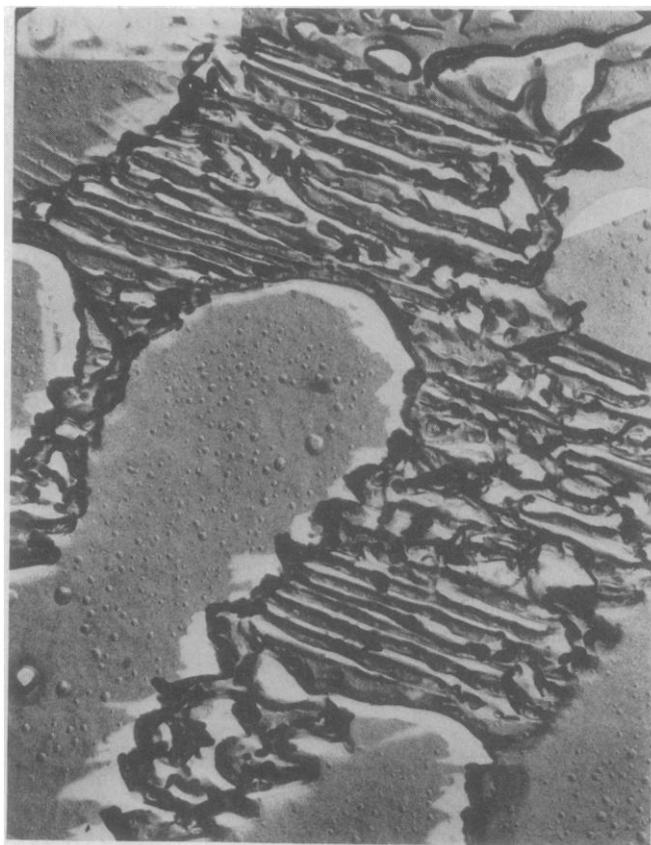


Fig. 1. (●, ○) Debye temperature  $\theta_D$  and (◇) electronic specific heat term  $\gamma$  for Ir-Y alloys. The open circle is an extrapolated point.

Fig. 2. Transmission electron microscopy replica of  $\text{Ir}_{0.95}\text{Y}_{0.05}$  showing the lamellar eutectic together with elemental iridium ( $\times 24,000$ ).



functions of the yttrium concentration.

The trend toward an enormous reduction of  $\theta_D$  becomes evident with as little as 1 percent Y, while  $\gamma$  remains almost unchanged throughout most of the range. The rapid decrease in lattice stiffness is in parallel to a rapid decrease in the melting temperature of Ir, as observed in most Ir-rare earth systems, as well as to a change in physical properties. The relative constancy of  $\gamma$  suggests little change in the electronic structure from that of iridium. The change in lattice stiffness is thus predominantly responsible for this extraordinary enhancement of superconductivity, an effect which is not limited to iridium metal (5).

Many of the results in the past for binary superconductors that did not fit with either the electron-to-atom ratio or crystallographic considerations are now readily understood by the presence of superconducting eutectics and their changed phonon structures. Enhancement of superconducting transition temperatures has been observed by other investigators, but never to the extent found in the iridium-yttrium system. Of particular interest are the investigations of the Ti-Mo (6) and Zr-Mo (7) systems. The well-known In-Sn and Pb-Bi alloys also fall in this category. In all of these systems the existence of a superconducting eutectic is the probable reason for their enhanced superconducting  $T_c$ .

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## Tumor-Promoting Phorbol Esters Stimulate Hematopoietic Colony Formation in vitro

**Abstract.** *Tumor-promoting phorbol esters stimulated mouse bone marrow cells to form myeloid colonies in agar cultures without added colony-stimulating factors. The colony-stimulating ability of various phorbol esters correlated well with their ability to promote skin tumors in vivo. These results suggest that phorbol esters mimic the action of specific colony-stimulating factors that regulate growth.*

Tumor-promoting phorbol diesters such as 12-O-tetradecanoyl-phorbol-13-acetate (TPA) have the ability to promote tumor formation in the skin of mice previously treated (initiated) with a sub-optimal dose of a chemical carcinogen (1). Phorbol esters exhibit a wide variety of effects in vitro on cultured cells, such as stimulation of DNA synthesis and cell proliferation (2-5), either inhibition (6-8) or induction (9-11) of terminal differentiation, induction of plasminogen activator and other enzymes (5, 12), and changes in cell membrane properties (13-15). In many studies the phorbol esters seem to produce effects that are normally induced by the action of a natural growth regulator (14). For example, TPA mimics a number of the biologic effects produced by epidermal growth factor (EGF) and apparently does so by altering the function of cell surface receptors for EGF (14, 15).

One culture system in vitro that has a well-characterized requirement for a growth-regulating factor is the soft agar cloning technique for granulocyte-macrophage colony-forming cells, also called colony-forming unit culture (CFU-C) (16). In this system, mouse bone marrow cells form colonies of granulocytes and macrophages (or monocytes) only in the presence of added growth regulating factor, called colony-stimulating factor (CSF). Biologically active CSF has been purified from medium conditioned by L cells and appears to be a glycoprotein of molecular weight 65,000 (17). Many other active CSF preparations have been reported and partially characterized [for review, see (18)], but little is known about structural details of CSF molecules or their active sites. We report here that tumor-promoting phorbol esters (but not their inactive analogs) stimulate mouse bone marrow cells to form hematopoietic colonies in agar culture without added CSF.

Because of the suggestion that phorbol esters imitate the action of growth regulators (14), we tested their effect on agar cultures of mouse bone marrow cells. Figure 1 shows that freshly isolated mouse bone marrow cells formed colonies in soft agar in the presence of  $5 \times 10^{-8}M$  TPA (without added CSF). The

TPA-stimulated colonies were quite uniform, discrete aggregates of 50 to 500 cells; by contrast, colonies stimulated by L cell-derived CSF (LC-CSF) (17) were more loosely arranged aggregates of 50 to 10,000 cells. Figure 1 shows that with increasing numbers of marrow cells plated, there were increasing numbers of colonies formed, although for TPA-stimulated colonies, linearity was observed over a more narrow range of cell numbers than for LC-CSF-stimulated colonies. Figure 1 also shows that the target cell for the TPA effect was abundantly present in the marrow nonadherent cell fraction. Depleting the marrow population of cells that adhere to plastic at 37°C enriched the sample for TPA-stimulated colony-forming cells to about the same extent as for LC-CSF colony-forming cells, consistent with the possibility that the target cell for the TPA effect is the same as that for LC-CSF.

To characterize the cells in the TPA-stimulated colonies we removed intact single colonies by aspiration into micropipettes and transferred them to glass slides. After air-drying and staining them with aceto-orcein, we examined the colony cells microscopically (19). In addition, using other cultures, we dehydrated the agar matrix and stained the colony cells in situ and then examined them under an inverted microscope (20). In three independent experiments, 80 to 90 percent of colonies were entirely composed of cells with the characteristics of mature macrophages, and 10 to 20 percent of colonies also contained a variable percentage of monocytes and neutrophils.

To harvest large numbers of colony cells for further examination, we also cultured fresh marrow cells in methylcellulose medium (21) containing  $10^{-7}M$  TPA. Wright-stained preparations were made of cells harvested from these cultures by dilution and washing. In differential counts of 200 cells on slides prepared from six cultures we found that  $81 \pm 4$  percent were of the monocyte-macrophage type; remaining cells were neutrophils or immature myeloid cells. When harvested colony cells were tested further, more than 60 percent showed firm adherence to plastic petri dishes in 1 hour at 37°C. Colony cells were also