The following observations are made from figure 1:

(i) All resistance vs temperature curves have a slight shoulder in the transition temperature range
(ii) The pressure shift of T_c (onset) T_{co} and T_c (final) T_{cf} is very small
(iii) The superconducting transition of the title compound terminates at 77 K at atmospheric pressure
(iv) (dR/dP) changes with increasing pressure.

The variation of transition temperature with pressure is shown in figure 2. T_{co} and T_{cf} were determined and plotted to observe the pressure dependence.

The pressure dependence of T_{co} and T_{cf} is not so large when compared with that in the La–Ba–Cu–O system. However, T_{cf} shows a maximum at 2, 3 and 4 GPa (figure 2).

The AC susceptibility down to 5 K was determined using the closed cycle refrigerator. The variation of χ_{ac} with temperature is shown in figure 3. The bulk sample exhibits a large diamagnetic signal at temperatures below 98 K. When the sample was powdered, the diamagnetic signal was reduced to 1/4 of the signal for the bulk sample at 5 K. This implies that the sample possesses superconducting phase at $T = 98$ K only on the surface and/or given boundaries[4]. It is also interesting to note that even for a solid pellet the diamagnetic susceptibility reaches a limiting value only at 30 K though the resistivity drops to zero at 77 K.

The interesting feature in figure 1 is the resistance behaviour in the normal conducting state. The transition temperature changes with increasing pressure. The positive sign of (dR/dT) at low pressures becomes negative at a certain pressure between 1 GPa and 2 GPa. T_{co} shows a faint maximum

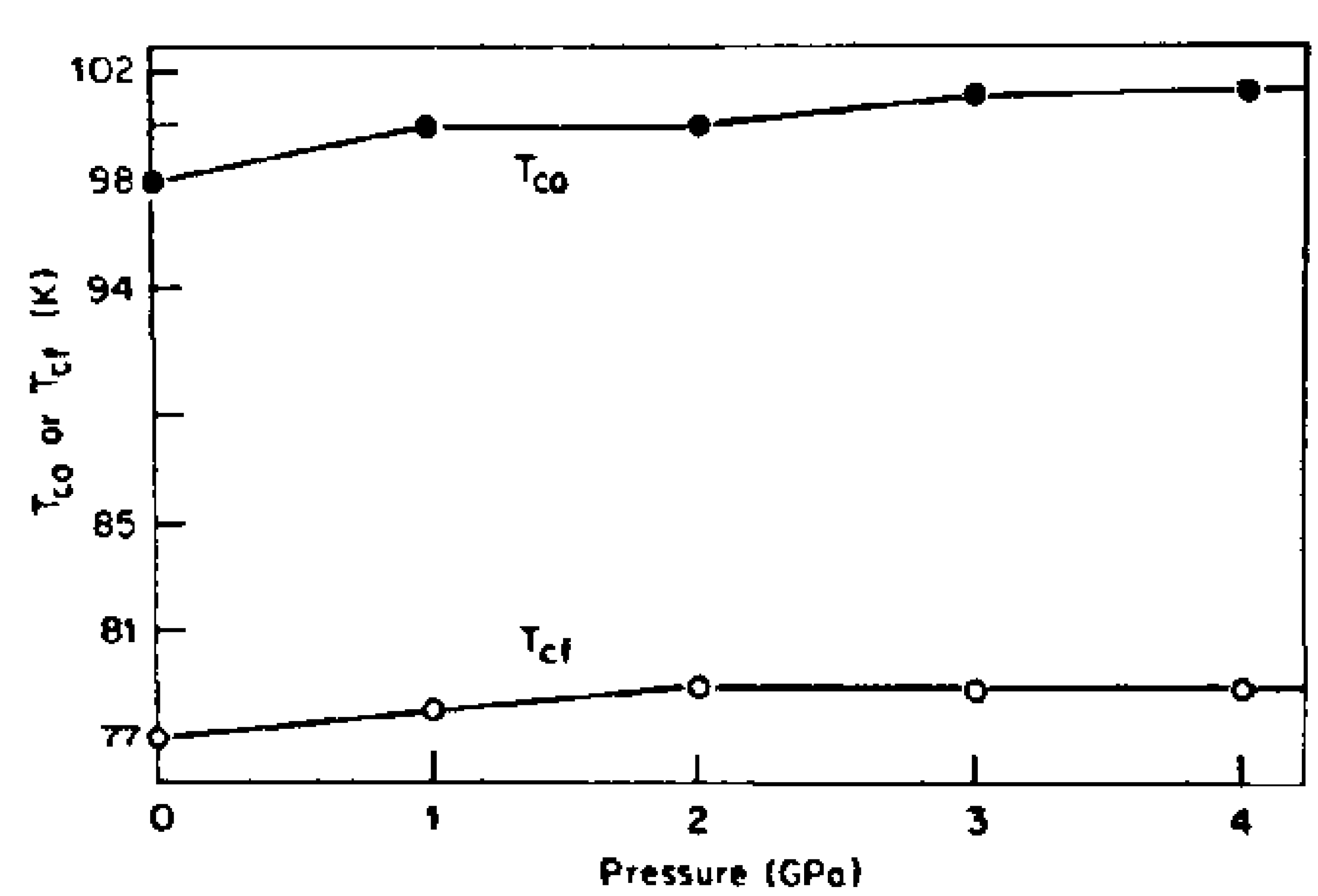

Figure 2. Pressure dependence of T_{co} and T_{cf} for $Ba_2Y_{0.5}La_{0.5}Cu_3O_{7-\delta}$.

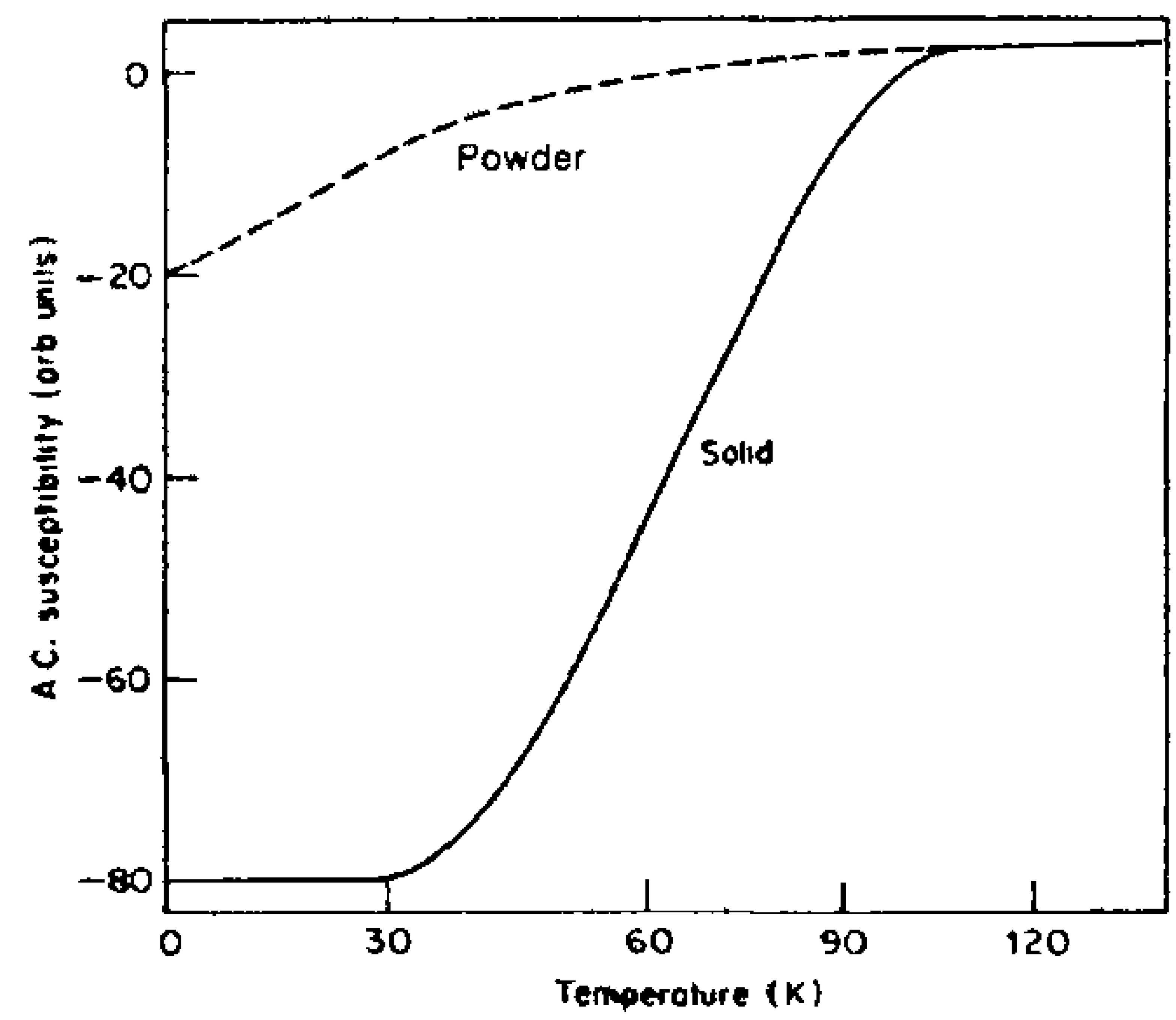

Figure 3. Variation of χ_{ac} with temperature for $Ba_2Y_{0.5}La_{0.5}Cu_3O_{7-\delta}$.

around 1 GPa as a whole. This maximum corresponds to the pressure at which the sign (dR/dT) in the normal state changes from positive to negative as mentioned earlier. Similar behaviour was also noticed by Akahama *et al.*[5]

Preparation of samples with different compositions and high pressure studies are in progress.

26 November 1988; Revised 11 August 1989

1. Bednorz, J. C. and Muller, K. A., *Z. Phys.*, 1986, **B64**, 189.
2. Chevalier, *et al.*, *J. Phys.*, 1987, **48**, 1619.
3. Natarajan, S. and Subba Rao, G. V., *Phase Transition*, (in press).
4. Takabatake, T., Takage, H., Wakazawa, Y. and Ishikawa, M., *Jpn. Appl. Phys.*, 1987, **26**, 502.
5. Akahama, Y., Endc, S., Noguchi, S. and Okuda, K., *Jpn. J. Appl. Phys.*, 1987, **26**, 871.

WHY HAS URANUS TOPPLED OVER?

R. K. KOCHHAR
Indian Institute of Astrophysics, Koramangala, Bangalore 560 034, India

URANUS is unique among the planets in the solar system because its spin axis lies in its orbital plane. Whereas the spin axes of the neighbouring Saturn and Neptune show a tilt of 27° and 29° from the normal to their orbital planes (similar to the case of

Earth and Mars), the tilt is 98° in the case of Uranus. We argue here that the peculiar rotation of Uranus is due to a tidal encounter of proto-Uranus with a massive passing planetary body in the early solar system, that may still be deleted as the tenth planet.

In analogy with the specific models for Jupiter and Saturn, one presumes that, irrespective of the actual mechanism of their formation, the outer Jovians Uranus and Neptune have also passed through three major phases from their origin to the present[1].

The first phase was characterized by a slow contraction of the planetary mass, on a Kelvin–Helmholtz time-scale of a few million years. In the second phase, the proto-planet underwent rapid collapse on a free-fall time-scale of a few years. During this phase, the shrinking proto-planet shed an equatorial disc, from which the satellite system formed. The third phase again involved slow contraction and is still continuing.

The present-day parameters of Uranus are as follows: mass 8.7×10^{28} g, equatorial radius 2.5×10^9 cm, oblateness 0.024, rotation period 17.24 h, angular momentum $\sim 2 \times 10^{43}$ g cm^2 s^{-1}. Our starting point however is an extended proto-Uranus that is yet to go into free fall. It is slowly rotating about an axis that, like in Saturn and Neptune, has an unexplained yet acceptable tilt of 28°.

At this stage the proto-planet of mass M and semi-major axes $a_1 = a_2 > a_3$ undergoes a tidal encounter with a planetary body of mass M' passing by with a velocity $\mathbf{v}$ and at a pericentric distance $\mathbf{p}$. The perturber transfers to proto-Uranus an angular momentum whose components are[2]

$$J_i = \frac{2GM'}{p^2 v}(I_{kk} - I_{jj})\alpha_{jk}. \qquad (1)$$

Here the indices i, j, k cyclically take the values 1, 2, 3. I_{ij} is the moment of inertia tensor of the proto-planet. $\alpha_{jk} = 2\hat{p}_j\hat{p}_k + \hat{v}_j\hat{v}_k - \delta_{jk}$, with $\hat{\mathbf{p}}$, $\hat{\mathbf{v}}$ being unit vectors along $\mathbf{p}$, $\mathbf{v}$ respectively: $\mathbf{p}\cdot\mathbf{v} = 0$.

Equation (1) has been derived using impulse approximation[3] and generalizes Peebles' well-known result[4] derived in the context of proto-galaxies. Note from equation (1) that, if the proto-planet is axi-symmetric, the transferred angular momentum would be about an axis in the equatorial plane:

$$J = \frac{1}{5} e^2 GM \left(\frac{a_1}{p}\right)^2 \frac{M'}{v}, \qquad (2)$$

where we have ignored the angular dependences. Here e is the eccentricity of the proto-planet: $a_3^2 = a_1^2(1 - e^2)$. If this tidally introduced angular momentum is about three times the initial angular momentum, which is about the perpendicular axis, then the net angular momentum would make an angle of 70° with the original direction so that, now, rotation would be about an axis tilted at 98° to the normal to the orbital plane. It is this axis that would be the new axis of symmetry, and satellite disc would form in the new equatorial plane.

There are no clues to the parameters of the tidal encounter. The proto-planetary mass however would not have been much different from the present-day Uranian mass. (It would have been slightly higher, see below.) If proto-Uranus had an eccentricity of 0.7 (corresponding to an oblateness of 0.3), and if the encounter was a grazing one: $p = 2a_1$, we can write from equation (2),

$$J = 4 \times 10^{42}\ \frac{M'/M_E}{v/\text{kms}^{-1}}\ \text{g cm}^2\ \text{s}^{-1}, \qquad (3)$$

where M_E is the mass of the earth.

If this angular momentum is to correspond to the present-day angular momentum of Uranus, the dimensional parameter M'/v should have a numerical value of 5. Thus the perturbing body could have been a $5M_E$ planetary body moving with a velocity of 1 km s^{-1}; or even a $100M_E$ body with a velocity of about 20 km s^{-1}. The tidal encounter would add to the internal energy of proto-Uranus[5]

$$\frac{\delta U}{|U|} = \frac{GM'^2}{pv^2 M}\left(\frac{a_1}{p}\right)^3.$$

Assuming the pericentric distance p to be twice the proto-planetary equatorial radius, which in turn is set equal to ten times the present Uranian radius, we see that $\frac{\delta U}{|U|} \sim 1$, so that proto-Uranus would not be disrupted. The outer layers of proto-Uranus may however be torn off as a result of this close, though brief, encounter.

The outer Jovians are indeed enigmatic. Mostly rock and ices, both Uranus and Neptune are short of hydrogen and helium gases. Uranus has peculiar rotational properties, even though its satellite system is normal. On the other hand, while Neptune itself is normal, it has but two pre-Voyager2 moons, both irregular. Additionally, the Pluto-Charon system may be displaced Neptunian moons.

Already the tilted spin axis of Uranus has been attributed to the impact of an $\sim 2M_E$ planetary body on proto-Uranus[6]. Numerical experiments[7] have shown that the properties of the present Neptunian moons and the Pluto–Charon system can be understood in terms of the tidal encounter of Neptune with a 2–5 M_E planetary body.

The idea of a perturbing body (with a dimensional mass/velocity of 5) in the outskirts of the solar system has many attractions. As we have seen, it can explain the tilt of the Uranian spin axis. This perturbing body would take 10–100 years (depending upon its velocity) to move to the Neptunian orbit. If during this time Neptune has already formed its equatorial disc, then the tidal effect of this outgoing can explain why the two Neptunian satellites became irregular and Pluto–Charon heliocentric. And if the body had a mass of $100M_E$ it can account for the missing gas that should otherwise have enriched the outer Jovians.

If the perturber had a very small velocity (and a low mass), it would end up as a satellite of Uranus. This is ruled out because of the extreme regularity of the Uranian satellite system, which precludes a captured satellite. If the perturber had a velocity of about $7\,km\,s^{-1}$, it would be bound in the Sun's gravitational potential, and should be detectable as a yet undiscovered planet at a large heliocentric distance.

I thank N. C. Rana, P. M. S. Namboodiri, P. Venkatakrishnan and T. P. Prabhu for discussions; and a referee for criticism.

21 June 1989; Revised 18 August 1989

1. Pollack, J. B., *Annu. Rev. Astron. Astrophys.*, 1984, **22**, 389.
2. Som Sunder, G., Ph.D. thesis, Osmania University, Hyderabad, 1985.
3. Lin, D. N. C. and Paploizou, J., *Protostars and Planets II*, (eds) D. C. Black and M. S. Mathews, Univ. of Arizona Press, 1985.
4. Peebles, P. J. E., *Astrophys. J.*, 1969, **155**, 393.
5. Alladin, S. M. and Narasimhan, K. S. V. S., *Phys. Rep.*, 1982, **92**, 339.
6. Stevenson, D. J., In: *Uranus and Neptune*, (ed.) J. T. Bergstralh, NASA CP 2030, 1984.
7. Harrington, R. S. and van Flandern, T. C., *Icarus*, 1979, **39**, 131.

BEDDING PLANE FAULT IN THE KALADGI ROCKS, BASIDONI, BELGAUM DISTRICT, KARNATAKA STATE

N. W. GOKHALE and G. S. PUJAR
Department of Geology, Karnatak University, Dharwad 580 003, India

DEVELOPMENT of a bedding-plane fault in the quartzarenitic rocks of the Kaladgi Group at Basidoni (16°51′25″N, 75°13′30″E), situated 18 km north-east of Saundatti, is evidenced by the development of a bluish-green pseudotachylyte, covering an area of 4500 m^2. The layer of pseudotachylyte is sandwiched between low-dipping quartzarenites. Striations and grooves trending N 70°E–S 70°W and N 30°W–S 30°E, and shears trending N 35°W–S 35°E (most frequent), N 70°E–S 70°W (intermediate frequency) and N 70°W–S 70°E (least frequent) are associated with the bedding-plane fault.

Several workers[1–5] have studied different parts of the Kaladgi basin, but there is no mention of such a fault by them. Angular unconformity is clearly noticed between the Kaladgi and the underlying Archaean gneisses. Two kilometres north-west of Basidoni, exposures of 80 m-thick pink quartzarenites dipping 4–5° due S 20°E are characterized by the presence of a thin (1 cm) veneer of glassy, bluish-green pseudotachylyte (figure 1). The bedding-plane fault dips gently (2–3°) due south-east. Pseudotachylyte layers are also noticed in the beds of quartzarenites occurring below the one shown in figure 1. In the vicinity of psuedotachylyte the rocks are found to be actively sheared in several directions.

The development of pseudotachylyte in the quartzarenites and the association of striations, grooves and shear planes in the vicinity of psuedotachylyte support the existence of a bedding-plane fault. The striations indicate displacement on the fault plane in two directions, viz. N 70°E–S 70°W and N 30°W–S 30°E. However, considering the higher frequency of striations trending N 70°E–S 70°W, it is suggested that greater/frequent movement might have taken place in this direction. Considering the fact that striations trending N 30°W–S 30°E are obscure, it may be surmised that the movement in that direction occurred at an earlier period and consequently the striations have become obscure.

The development of several parallel layers of pseudotachylyte one below the other probably indicates the presence of several 'parallel bedding-plane faults'.