Density disparity – A core issue about earth's core

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Earth's core, its formation and other aspects, have been subjects engaging scientists in lengthy debates. The widely accepted view visualizes that after accretion, early earth underwent gradual increase of its internal temperature owing to lesser rate of heat dispersal, compared to heat produced internally by compression and radioactivity. This steady accumulation of heat attained temperature of melting point of iron at depths of 400–800 km, by the time earth was 1.0 billion years old. A second view holds that core separation occurred progressively while accretion was still in force, within a few hundred million years. Iron being heavier and more abundant (~ 35%) than other common elements [O(30%), Si(15%), Mg(13%), Ni(2.4%), S(1.9%), Ca(1.1%), Al(1.1%)] making up 99% of earth, it gravitated towards the centre, displacing lighter materials[1] (Figure 1). The partitioning of elements inevitably led to a chemical zonation of earth, the process controlled, more by chemical and physical properties (densities and melting points) of compounds formed, than by properties of elements that formed them. As a result, a light crust depleted in iron but enriched in O, Si, Al, Ca, K and Na was created; the mantle region, between the core and the crust, carried with it magnesium–iron silicates. It was believed that heavier elements (noble metals) like Au, Pt, Pd, Os, Ir, Rh, Re, which do not form compounds with O or Si, sank to the core. Other heavy metals like U, Th easily combined to form silicates and oxides and concentrated in outer layers of earth. A large proportion of the volatile, inert, rare and noble gases were believed to have escaped from the early earth.

The core, which constitutes roughly a third of earth's mass, is solid at its centre (about 4% of its volume) and liquid towards the outer regions. This liquid outer core is slowly crystallizing from the centre towards periphery. Among the many issues that have been generating considerable debate about the core, is its density. The latter, which increases with depth, is about 10 g/cc at the mantle–core boundary and 13 g/cc at the centre. However, calculations indicate that its density is about 10% lower than it should be for pure Fe or Fe–Ni at core pressures (364 GPa at the centre)[2]. Also at the mantle–core transition zone, the observed density is about 10% higher than expected, which has led to the suggestion of a possible intermixing of the lighter mantle material with heavier outer core material[3]. This intermixing view is also strongly supported by the higher amounts of the noble metals than expected in the mantle since these metals were supposed to have partitioned into the core during earth's early stages of evolution[4]. At one time, it was even thought that the core may be metallic hydrogen but this view was later dismissed as the very high pressures needed to squeeze hydrogen to metallic state is not prevalent in the core. Incorporation of lighter elements, soluble in Fe and stable at core pressures, was therefore suspected for the observed density deficit. Experimental research, during the 1960s, on the solubility of elements at core P–T conditions led investigators to propose Mg, C, H, O, S or Si as probable elements incorporated into the core. Oxygen, H and C were, however, considered less likely; oxygen, because of its low solubility in Fe, apart from the extreme instability of Fe–FeO alloy phases[5], and C and H because of their volatility, particularly H, which is considered to have escaped along with inert rare gases during early stages of earth formation.

High pressure experimental studies, last year, by Parker *et al.* (Pennsylvania State University) listed some of the alkali elements as likely candidates to account for the density anomalies. They showed that the lack of affinity of some of the alkali elements like K, Rb or Cs to react with transition metals like Fe, Ni, or Co disappear at core P–T conditions and they could be made to react[6,7]. They demon-

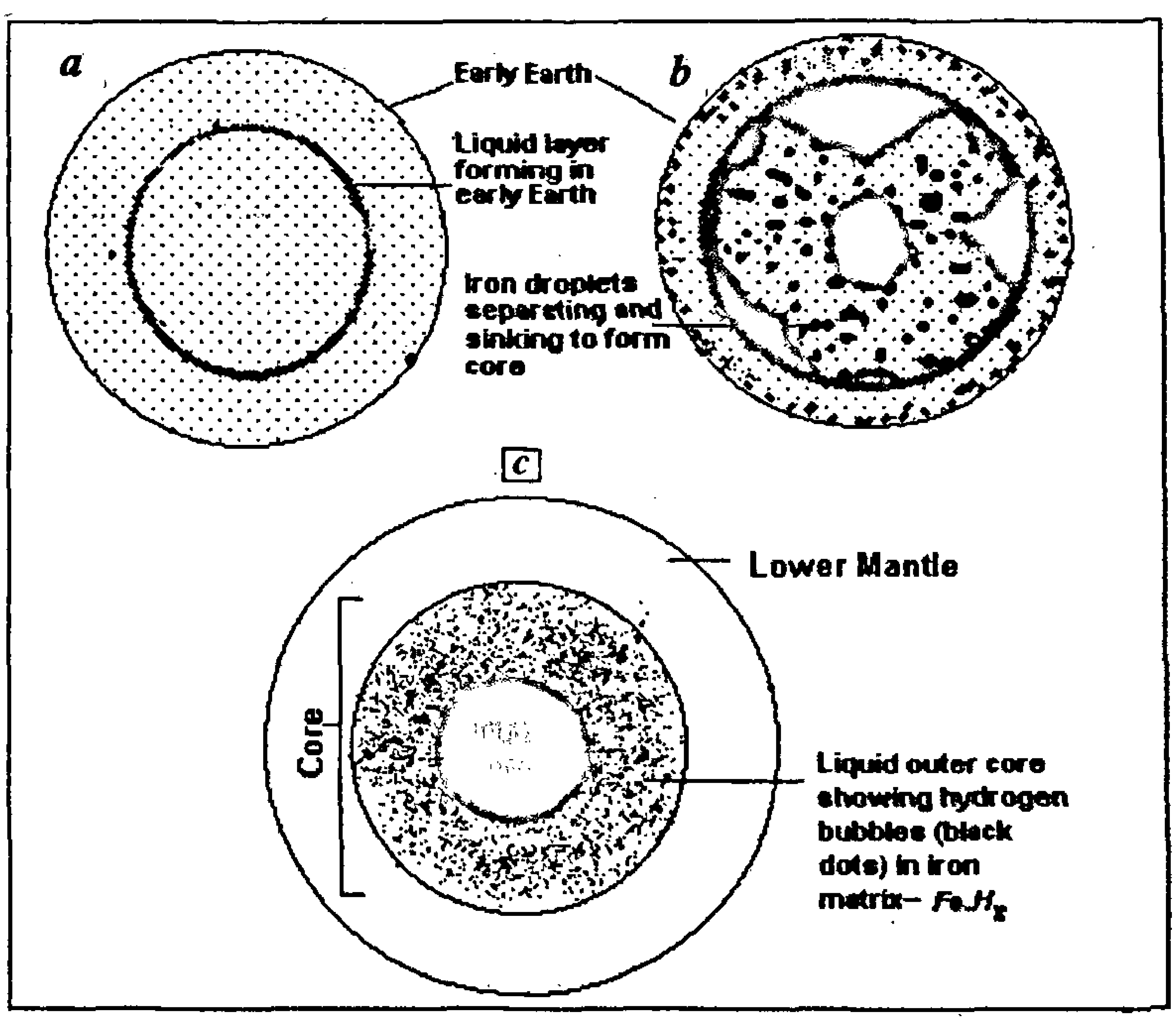

Figure 1. (*a*), Melting of iron in early earth due to internal heating leads to heavy liquid layer (iron ponds) from which (*b*) drops of iron develop and sink to centre. (*c*) H bubbles, released as drops in iron matrix, are prevented from diffusing outwards.

strated the chemical union between these normally incompatible groups, by synthesizing an intermetallic compound of K and Ni at pressures of the order of 310,000 atmospheres (31 GPa) and above at temperature of 2500 K developed in a laser heated diamond anvil. This unconventional union of K and Ni prompted them to speculate that 'since charge densities of Fe and Ni are similar, despite lower electronegativity and work function of Fe', K and Fe should also react under core pressure and suggested possibility of K as a probable component to lighten the core density[6,7]. The other view that Si or S may be the light element in the core[8,9] has problems with respect to oxidation states. Sulphur alone cannot satisfy the observed deficiency in core density without incorporation of another lighter element. Thus Si and S are suggested as the density-lightening elements and that early core formation is thought to have taken place under reducing conditions, facilitating dissolution of Si in the metallic core. Progressively, the conditions became oxidizing with addition of S to oxidize Fe to silicate[5].

Now in a very recent work, Takuo Okuchi (Department of Earth and Planetary Sciences, Tokyo University, Japan) has resurrected the disfavoured H and experimentally demonstrated how indeed it can be the dominant element lightening the density of molten iron in the outer core[10], though not as solid H as was once thought. He feels that contrary to the notion that considerable H escaped during the early degassing phase, it was actually incorporated into the segregating iron core quite early in primordial earth. Okuchi envisages sequence of reaction thus: assuming an initial H_2O content of 2% in primordial molten earth, he proposed segregation of H and ferrous Fe from the primitive bulk through interaction of H_2O and metallic Fe. The H thus released, which estimates show is much more than what is contained in the hydrosphere, would have to dissolve into the core rather than diffuse and escape out of the earth. He has demonstrated these reactions experimentally under ultra high pressures generated in an uniaxial multi-anvil apparatus. The experiment is based on the fact that Fe and H react to form metallic hydride – FeH_x, a compound stable at pressures > 5 GPa, but decomposing at pressures lower than this. In order to determine the partitioning coefficient of this metal–silicate bond and extrapolate the parameters to core conditions and evaluate the reactions, he reacted mixtures simulating an ultrabasic bulk-composition of iron and silicate components. He used a mixture of metallic Fe, MgO, brucite ([$Mg(OH)_2$], silica glass (SiO_2), silicic acid ($SiO_2 \cdot 0.4H_2O$) and liquid H_2O under 7.5 GPa pressure and synthesized a solid compound $FeH_{0.33}$. This compound [m.p. between 1100 and 1200°C, about 600°C below that of Fe (melting point of Fe is reduced by addition of H)], melts to a liquid with a composition $FeH_{0.4}$ in molten silicate; but being immiscible in a silicate melt, it rapidly breaks down as large droplets, and being unstable at available ambient pressure, quickly decomposes further into H_2 and Fe. In this confined state, hydrogen released is incapable of diffusing out and hence remains in the core.

Okuchi feels that (i) metal–silicate melt partitioning of H in primordial earth had occurred at the 'bottom of magma ocean where molten metal may have stagnated as iron ponds'; (ii) Most of H_2O accreted to earth should have dissolved into the magma ocean; (iii) If the pressure at the bottom of the magma ocean was ≥ 7.5 GPa, more than 95% of H_2O accreted to earth should have reacted with Fe to form FeH_x; (iv) Iron pond then sank to the core by large scale gravitational instability during which pressure and temperature adjacent to molten iron increased; (v) H partitioned into the molten iron at the bottom of magma ocean cannot return to silicate melt and should have gone to the core; (vi) This H would then reduce the density of iron in outer core by 5.5% and together with contribution from S (1.1%) and C (2.2–2.7%), the overall density reduction in outer core is ~ 9.9% which agrees with observed deficit. In the inner core also H may be the primary light element to explain the density deficit of about ~ 7.1%. However, Wood (Department of Geology, University of Bristol) observes that Okuchi's single stage model should be tested at realistic core pressures and actual core properties, in addition to testing the agreement of siderophile element depletion patterns accompanying FeH_x segregation[2].

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OPINION

Patents on life forms: the case for

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The interrelated issues of intellectual property rights (IPRs), patents, biopiracy and India's stand *vis-à-vis* the World Trade Organization (WTO) have generated considerable debate and controversy amongst the lay public, non-governmental organizations, the executive arm of government and parliamentarians alike.

India's decision in 1994 to be a signatory to the set of final agreements emanating from the Uruguay Round of Multilateral Trade Negotiations (including