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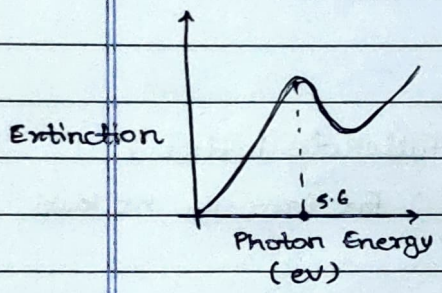
- Carbon nanotechnology
  - Fullerene
  - Carbon nanotubes
  - Graphene (single sheets from graphitic structure)

(The general class of carbon molecules including graphene and all the tube and balloon structures it forms on curling up are known as fullerenes)

- Optical spectrum of light coming from stars -



The peak at 5.6 eV is due to absorption from C_{60} present in interstellar dust

- Structure of C_{60} fullerene

(named after Buckminister Fuller) → (geodesic dome) ↗ resembles the structure of C_{60}

- 12 pentagonal, 20 hexagonal } arranged symmetrically to form a molecular ball
- Diameter = 0.7 nm

- Euler's Theorem $\{V - E + F = 2\}$

for C_{60} : $F = 32$, $V = 60$, $E = 90$

(acc. to this theorem, any closed shell will be produced by 12 pentagons, irrespective of the number of hexagons.)

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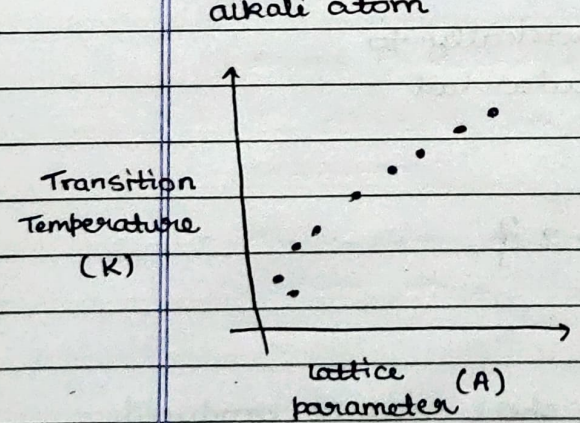
- Materials produced by assembling fullerene : Fullerite
  - The assemblies of pure fullerene molecules in condensed form as known as Fullerites.
  - Crystal structure of C_{60} is FCC
  - Separation b/w nearest-neighbour C_{60} is 1 nm.
  - held by weak Van-der-Waals forces
  - FCC crystal of C_{60} is an insulator.

(Fullerites are photosensitive, which makes it useful as a photoresist in lithographic processes.)

- Fullerides
  - (when other atoms are included in fullerite lattice)
  - (Alkali metal atoms (ex. Na, K, Cs ---) fit into the hollows left between the C_{60} cages)
  - (have remarkable property of superconductivity)

- Plot of transition temperature of A_3C_{60}, where A is an alkali atom



as the radius of the dopant alkali atom increases, the cubic C_{60} lattice expands and the superconducting transition temperature goes up.

(The superconducting transition temperature increases with increasing size of the alkali atom)

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- Magic numbers in larger fullerenes.
  - $[60 + (k \times 6)]$ atoms $k = 0, 2, 3, 4, \ldots$
  - for stable fullerene with n atoms.

    $\left\{ \text{number of hexagons} = \frac{n}{2} - 10 \right\}$

(There are especially stable numbers of atoms (special values of n) when the closed shell has a low-energy morphology. They as known as magic numbers)

- $k = 0$ (C_{60}), corresponds to first magic number.
- C_{540} (magic number $k = 80$)

- Other possible stable series
  - C_{70} peaks : most prominent peak after C_{60}
  - structure of C_{70} (25 hexagonal & 12 pentagonal faces)

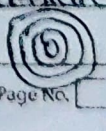
(including elliptical and tubular fullerenes -)
- $70 + 30k$ $(k = 0, 1, 2, 3)$
- $84 + 36k$ $(k = 0, 1, 2, 3..)$

- CNT (length : few μm
  diameter : as low as 1 nm)
  - stable carbon structure
  - rolled-up shell of graphene sheet (1-atom thick)
  - mainly made up of hexagonal rings.
  - high aspect ratio : $\frac{\text{length}}{\text{diameter}} > 1000$

Types

① Singled-wall CNT
diameter : 1 nm
band gap : 0-2 eV
Electrical conductivity can show metallic or semi-conductor behaviour)

② Multi-walled CNT
Interlayer distance : 3.4 Å
(a) Parchment model (b) Russian doll



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- Fabrication of CNT

(to produce SWNT, a small amount of cobalt, nickel or iron is used as a catalyst)

(no catalyst → nested tubes / MWNT)

- Discovery (Sumio Iijima)

diameter : 4-30 nm

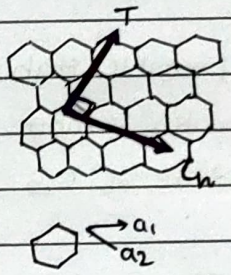
length : 1 um

no. of concentric walls : 2-7

- T : axis vector about which the sheet is rolled.

a_1, a_2 : basis vector of 2D unit cell.

C_h : circumferential vector, at right angles to T



- Chirality

- (refers to how tubes are rolled w.r.t the direction of the T vector in graphite plane)
- (the choice of axis angle produces changes in electronic properties).
- The chirality of nanotube is specified by circumferential vector $na_1 + ma_2$

- Classifications

(n,n) Armchair : T || c-c bond

(n,0) Zigzag : T not || C-C bond

(n≠m) Chiral : - T not || cc bond

: - nanotube has a helical / spiraling structure when viewed along its axis.

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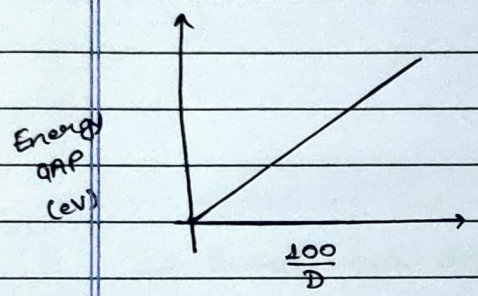
- Synthesis of carbon NT = 2/3 (semiconducting) + 1/3 (metallic)

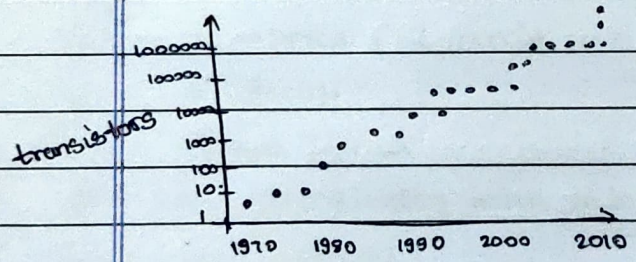
- all armchair (n,n) are conducting
- (n,m) tubes with [(n−m) = 3i] are almost metallic
- ((n−m) ≠ 3i) is semiconducting with bandgap ∝ 1/diameter (tube)

- Electrical Properties



as the diameter of the semiconducting nanotube increases, the bandgap decreases.

- Moore's law



exponential growth (doubling of components every 2 or 3 years) in ICs

- Graphene (single sheet of graphite, 2D honeycomb lattice arrangement of C atoms)

① High electrical current density
② high intrinsic mobility
③ high thermal conductivity
④ Optical transparency
⑤ Strength
⑥ one of the world's thinnest material
⑦ toughest 2D material
⑧ Highest surface area
⑨ Density of graphene (0.77 mg/m²)

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