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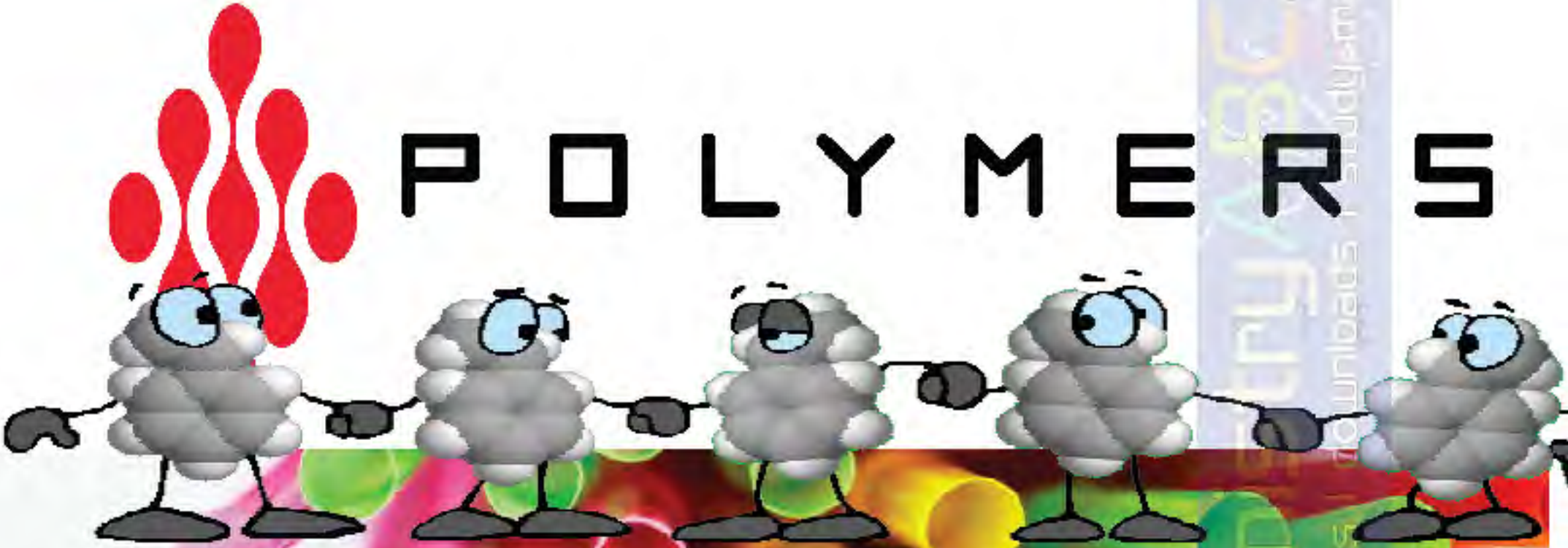
POLYMERS



BHAWANA (QUANTUM GIRL)

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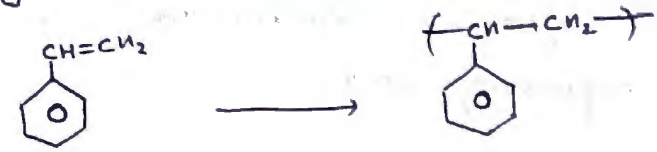
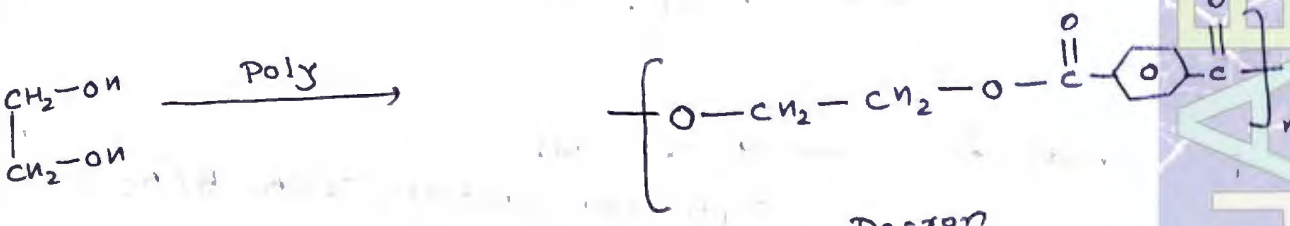
Polymers

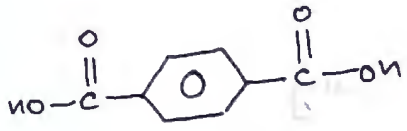
- Made from combination of two monomers.



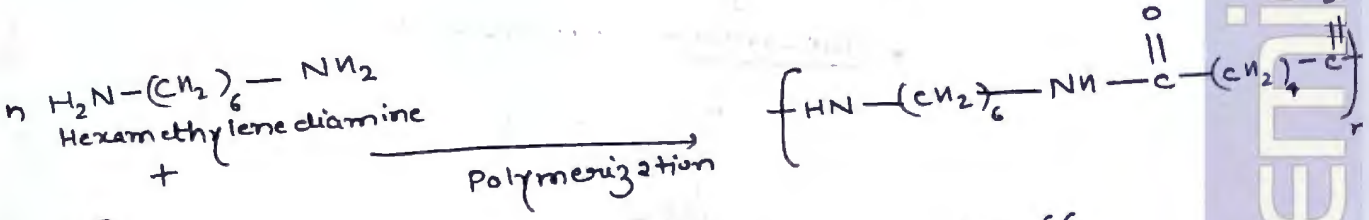
Styrene



Decron
PET



Pereptthalic acid



Nylon, 66

- Each polymer has a basic structure unit, that repeat it several times.
- Many of the polymer are prepared from only one type of monomer unit.

  e.g. Styrene (poly)
- With more then one polymer

  e.g. PET, Nylon 66

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Polymer (In terms of repeating unit)

→ Homopolymer (Only one type of monomer)

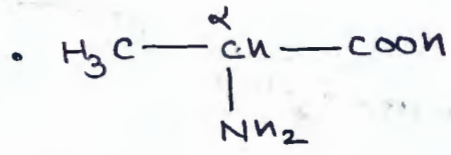
→ co-polymer (there are more then one 1 type of monomer as repeating unit.

Polymer (

→ Synthetic →

→ Natural (Polymer → protein, DNA, RNA, starch)

- Protein → • naturally occuring polymers
- Imp.
- Monomer - Aminoacid



α- Alanine

Polymerization →

$$n(CH_2=CH_2) \longrightarrow \{CH_2-CH_2\}_n$$

The no of repeating unit, that is repeated again & again, is called degree of polymerization.

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- a high molecular ~~wait~~ weight polymer is formed
- D.O.P generally represent the no of monomeric unit contained in the polymer, it is designated by 'p'. if molar mass of polymer is 'M' & 'm' is the molar mass of monomeric unit

Then

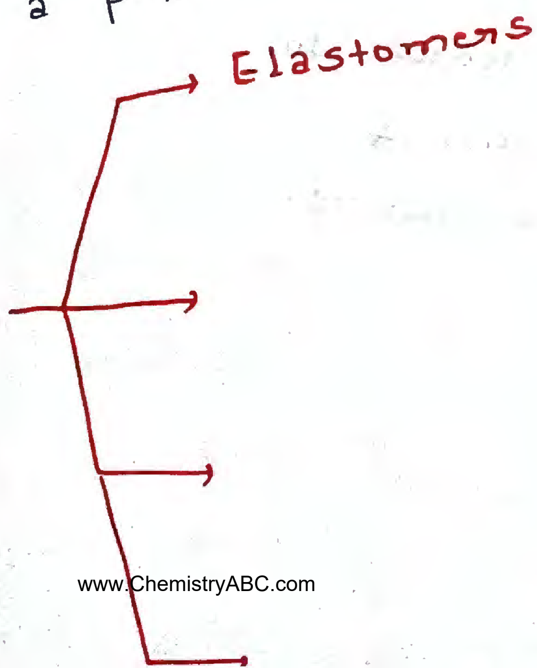
$$p = \frac{M}{m}$$

→ Natural rubber - is the polymer of isoprene (1,3- butadiene)

$$H_2C = \underset{\underset{CH_3}{|}}{HC} - HC = CH_2$$

→ Latex - dispersed phase in aqueous medium coagulated by acid coagulation method.

→ Isoelectric point is ~~weak~~ reached to a pH at 5.1 - 4.8



Elastomers.

- can be stretched
- weak intermolecular forces.
- Regain its original shape, when stress is removed.

e.g. vulcanized rubber.

- Natural rubber - has ~~no~~ poor elasticity & soft & sticky when heated & become permanently deformed.

However, when natural rubber is heated with 3-5% sulphur, it becomes more elastic.

Rubber — Vulcanization

Fibres →

- These have strong intermolecular forces.
- e.g. Polyamide (Nylon 66)
  Polyesters (PET/Decron)
- These forces also leads to close packing of chains & thus give crystalline nature.
- Have sharp M.P.

Thermoplastics :-

Easily softened repeatedly when heated & hardened when cooled. with a little change in their properties. The intermolecular forces are intermediate between Elastomers & fibres.

There is no cross linking b/w chains. Softening occurs when polymer chain move more & more freely because of the absence of cross-linking.

When heated form a fluid, which can be moulded into any desired shape & then col cooled.

E.g. Polyethylene, Polystyrene, PVC, Teflon.

Thermosetting polymers →

These are the polymers which undergo permanent change on heating, on heating they undergoes extensive cross linking & became hard & infusible Therefore they cannot be reused.

e. They are generally prepared from low molecular mass semifluid substances. The get highly cross linked to form hard, infusible & insoluble product.

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Cross-linking holds the molecule in place, so the heating doesn't allow them

e.g. Bakelite, Melamine formaldehyde resin.

Plasticizers :-

- PVC- made soft by di-n-butyl pthalates (plasticizers).

- Some other Plasticizers-
  - * Dialkyl pthalates.
  - * Cresyl pthalates.
  - *

Synthetic rubber -

Is any vulcanized rubber capable of getting stretched to about twice of its length.

on applying external force, returns to its original shape & size as external stretching force is removed.

Most of these polymers are derived from butadiene derivatives containing carbon carbon double bond.

Synthetic rubber are either

(i) Homopolymer of 1,3-butadiene

(ii) copolymer of - one 1,3-butadiene derivative + & other is buta

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So that the polymer has the ability of vulcanization.

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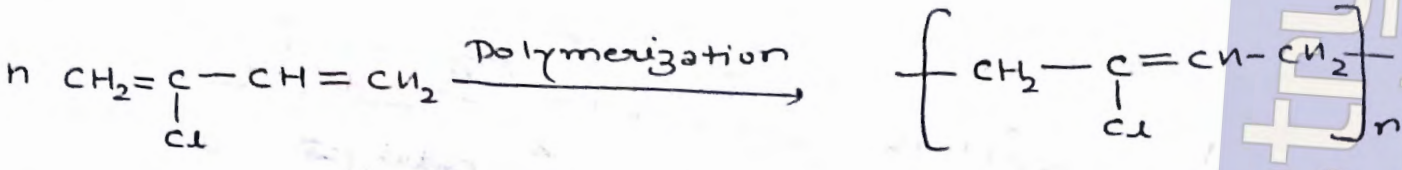
e.g. of Synthetic rubber

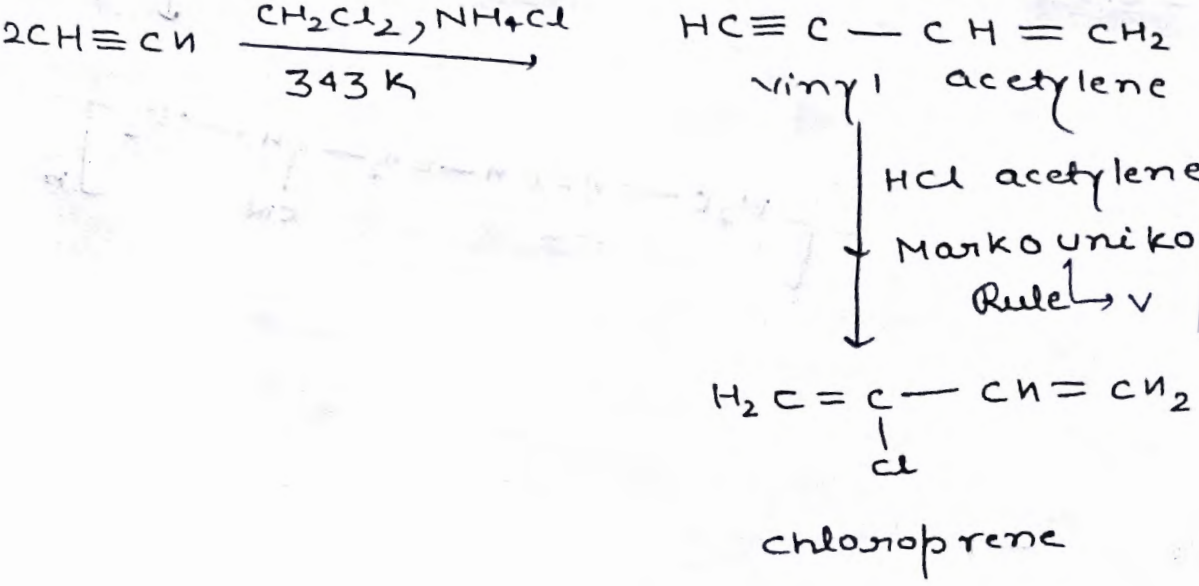
1. Neoprene
2. Styrene butadiene rubber (SBR), Buna-S
3. Acyronitrile butadiene rubber, (Buna-N).

It

Neoprene - It is prepared by free radical polymerization of chloroprene (A: (2-chloro, 1,3-butadiene)



Starting material of chloroprene is obtained by dimerization of acetylene by passing it through aq. solution of NH_4Cl



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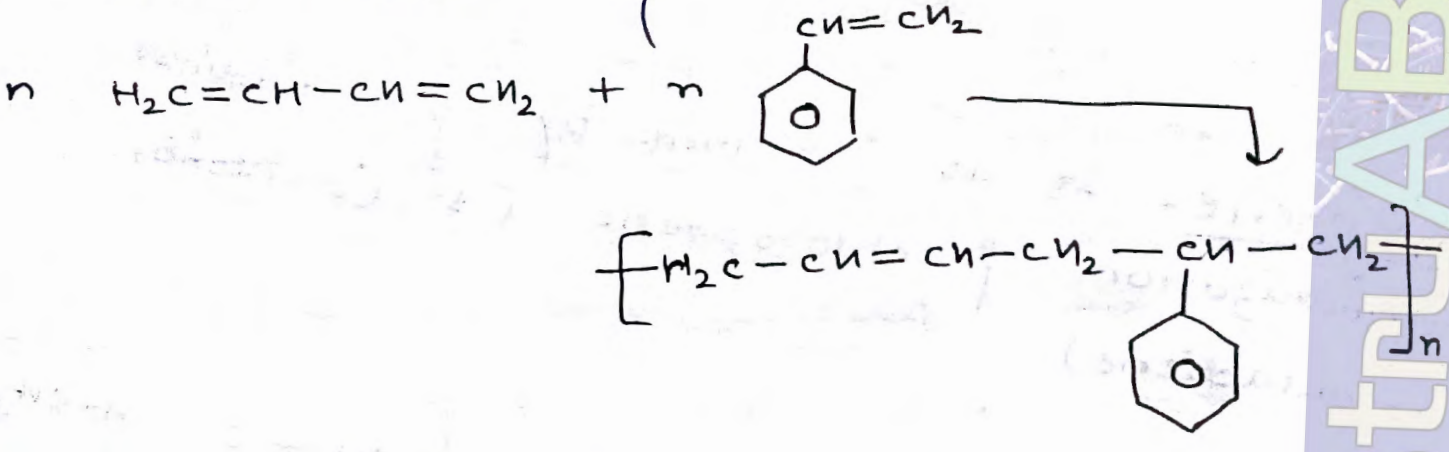
• Neoprene is ~~supreme~~ superior to natural rubber in its stability to its aerial oxidation & its resistance to vegetable oil, mineral oil & other solvent.

(2) Buna-S / Styrene butadiene rubber

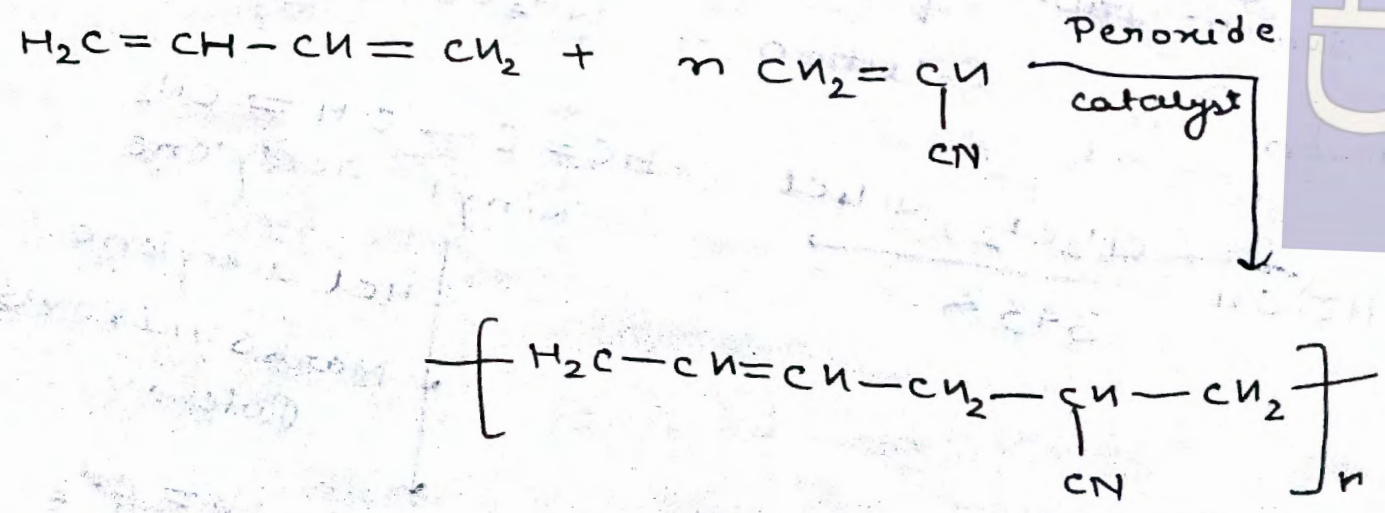
It is obtained by



(3) Acyronitrile butadiene / Buna-N-

In the presense of peroxide catalyst

~~$CH_2=CH-CN$~~



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Classification (on the basis of mo

- (1) Addition polymer or chain growth polymer
- (2) Step growth or condensation

(1)- Addition polymer-

formed by direct addition of repeated monomer without elimination of any byproduct is called addition polymer.

In this type monomer are unsaturated compound possesing double or triple bond.

- $n\ CH=CH_2 \xrightarrow{\text{Polymerization}} \left(CH_2-CH_2\right)_n$
- $n\ CH_3-CH=CH_2 \xrightarrow{\text{Polymerization}} \left(CH(CH_3)-CH_2\right)_n$
- $n\ CH_2=CH-Cl \xrightarrow{\text{Polymerization}} \left(CH_2-CH(Cl)\right)_n$
- $n\ CH_2=CH(CN) \xrightarrow{\text{Poly}} \left(CH_2-CH(CN)\right)_n$

Polyacrylonitrile
orlon

- $n\ (F_2C=CF_2) \xrightarrow{\text{Poly}} \left(CF_2-CF_2\right)_n$

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Polyethene → LDPE
Polyethene → HDPE

LDPE →

@ 350 - 570K (by ethylene, under high pressure)

in the presence of traces of oxygen or peroxide initiator, which initiate polymerization.

It consists of highly branched chain molecule, polyethene molecule do n't pack well, so it has low density. ($0.92\ gm\ cm^{-3}$)

- LDPE of moderate tensile strength.
- used in packing material & also used for insulation

HDPE →

$$n CH_2 = CH_2 \xrightarrow[6-7\ atm]{333-343K} -(CH_2-CH_2)_n-$$

Ziegler natta catalyst

$[TiCl_4 + Al(C_2H_5)_3]$

comparitevely low pressure compared previously beoz of presence of Z.N.C.

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This polymer consists of linear chain & molecule can closed pack in a space. & higher m.p.

& high tensile strength

- Almost unbranched.
- It's chain can be close packed in solid state, such close packing wouldn't be possible in case of branched LDPE. This is the reason why HDPE has higher density then the later.

PTFE (Polytetrafluoro ethylene) / Teflon

It is an addition polymer of tetra fluoro ethylene

$$n\,(CF_2=CF_2) \xrightarrow{\text{Polymerization}} \left[\begin{matrix} F & F \\ | & | \\ C & -C \\ | & | \\ F & F \end{matrix}\right]_n$$

- Inert
- Resistant towards heat & attacked by corrosive reagent such as acid & bases.
- It is bad conductor
- Used in Gaskets, pumps (to avoid leakage), oil seals etc.

PAN (Polyacyronitrile) orlon →

It is obtained by addition poly... catalyzed by peroxide

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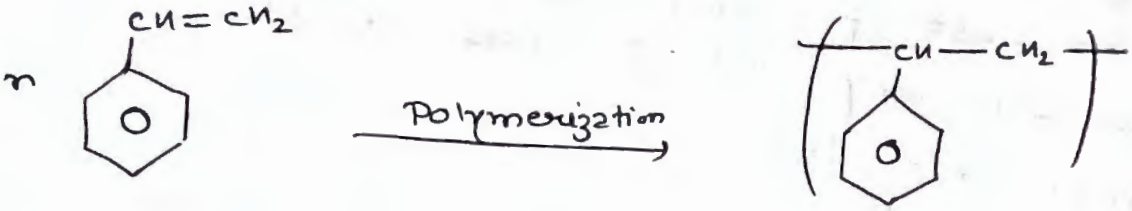
• $HC \equiv CH + HCN \xrightarrow{BaCN_2} H_2C=CH-CN$

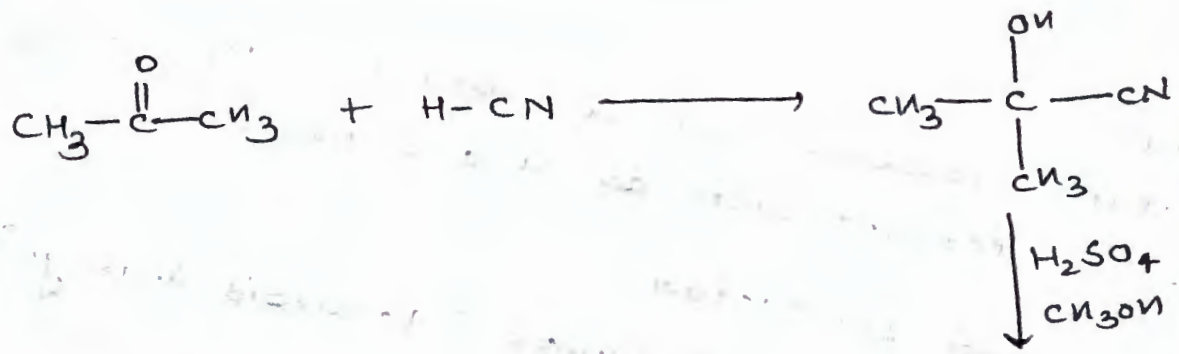
Vinyl cyanide

• $n CH_2=CH-Cl \xrightarrow{\text{Polymerization}} \left(CH_2-CH(Cl)\right)_n$



Polymethyl methacrylate –

This is obtained by polymerization of P. MMA (methyl methacrylate). The monomer is prepared from acetone



$CH_3-C(=O)-CH_3 + H-CN \longrightarrow CH_3-C(OH)(CH_3)-CN$

$\xrightarrow[CH_3OH]{H_2SO_4}$

$CH_2=C(CH_3)-C(=O)-O-CH_3 + (NH_4)_2SO_4$

Methyl methacrylate.

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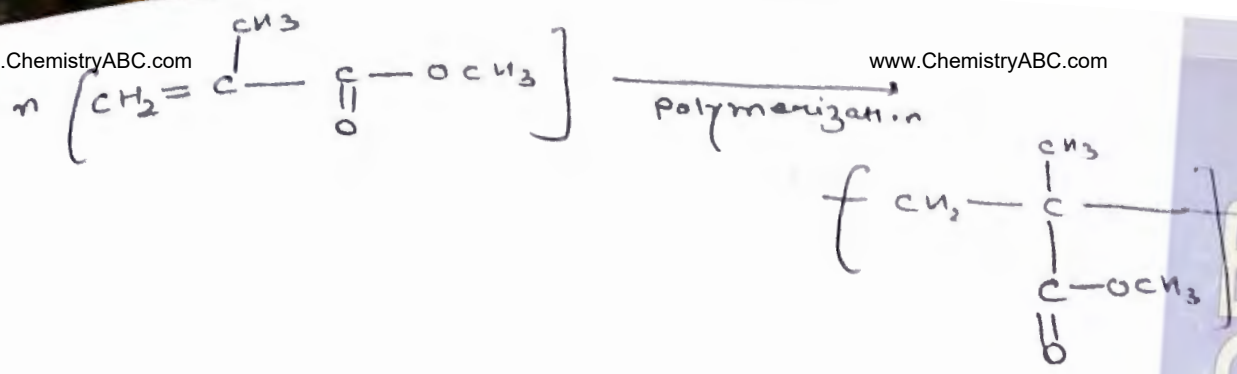


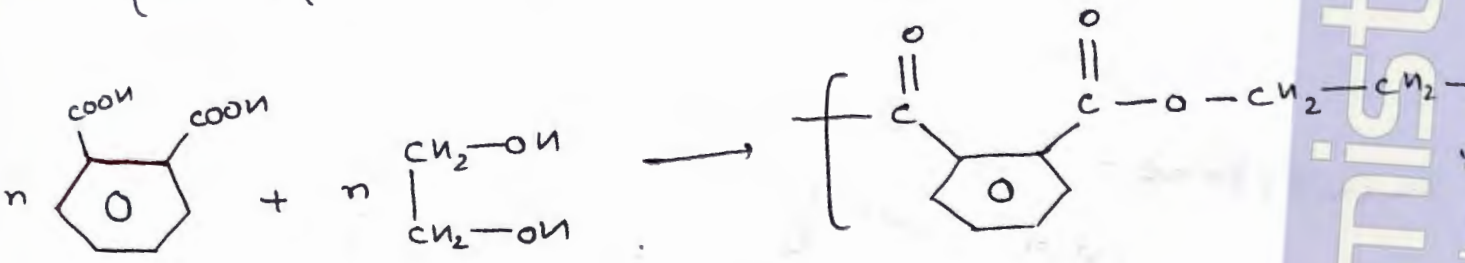
used in

- Aircraft windows, lens, transparent domes.
- Commercial name – Plexiglass.

Condensation Polymer

Glyptal →

- It is formed by the monomer of ethylene glycol & pthalic acid.



used in

* Manufacture of paints & lacquer. (a liquid that is spread on wood or metal, that dries to form a hard & shiny surface.

It is used as a protective coating

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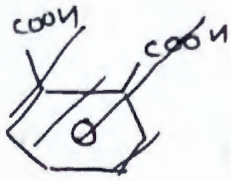
Kevlar →

- Monomer - (1,4 phenylene diamine) & tere pthalic acid in a



Used →

- Making combat helmets.
-

Polyesters -

- Contain ester linkages
- These are condensation product of dicarboxylic acid & diols.

e.g. Terylene & Dectron

↳ Polymer of ethylene glycol & tere pthalic acid, obtained by heating a mixture @ 420 - 460 k in the presence of zinc acetate - antimony trioxide as a catalyst.

- Used in blending with cotton

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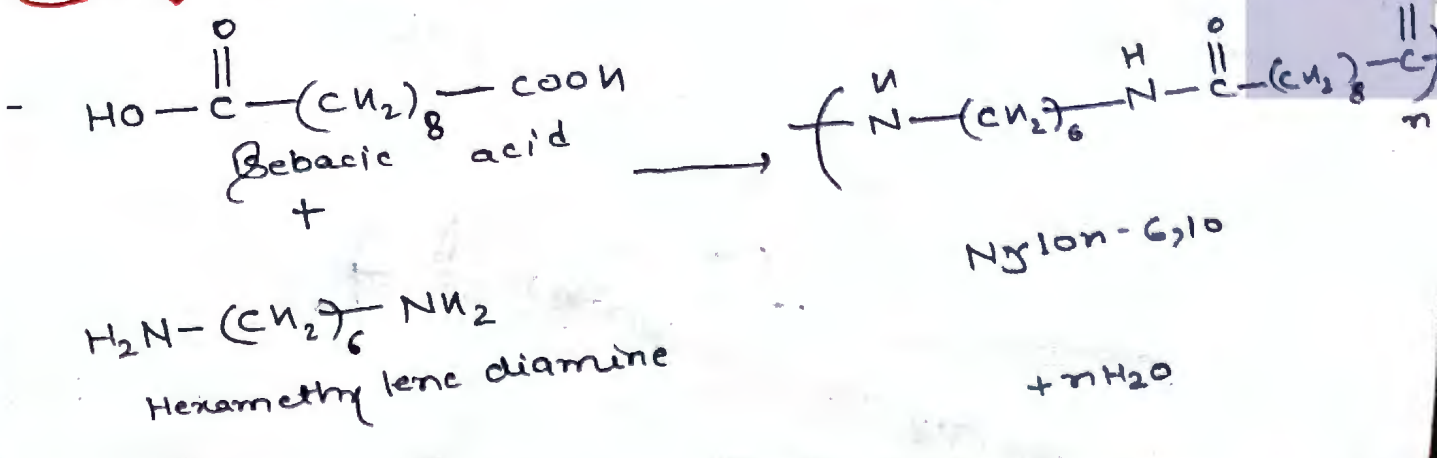
- It is also used in making magnetic recording
  ↙
  Terylene tapes.
- ~~These polymers have~~

Polyamides:-

These polymers have amide linkages in chain, these are popularly known as nylon (nylon 66, nylon 6, nylon 6,10)

- Nylon 66- Hexamethylene diamine + Adipic acid
- Protein is an example of polyamide.
  If a protein contain n-amino acids it has (n-1) amide linkages.
- It is used fo making bristles & also used in textiles for making seeds.
- It is blended with wool.
- Manufacture of ~~cord~~ cords

- Nylon 6,10 →



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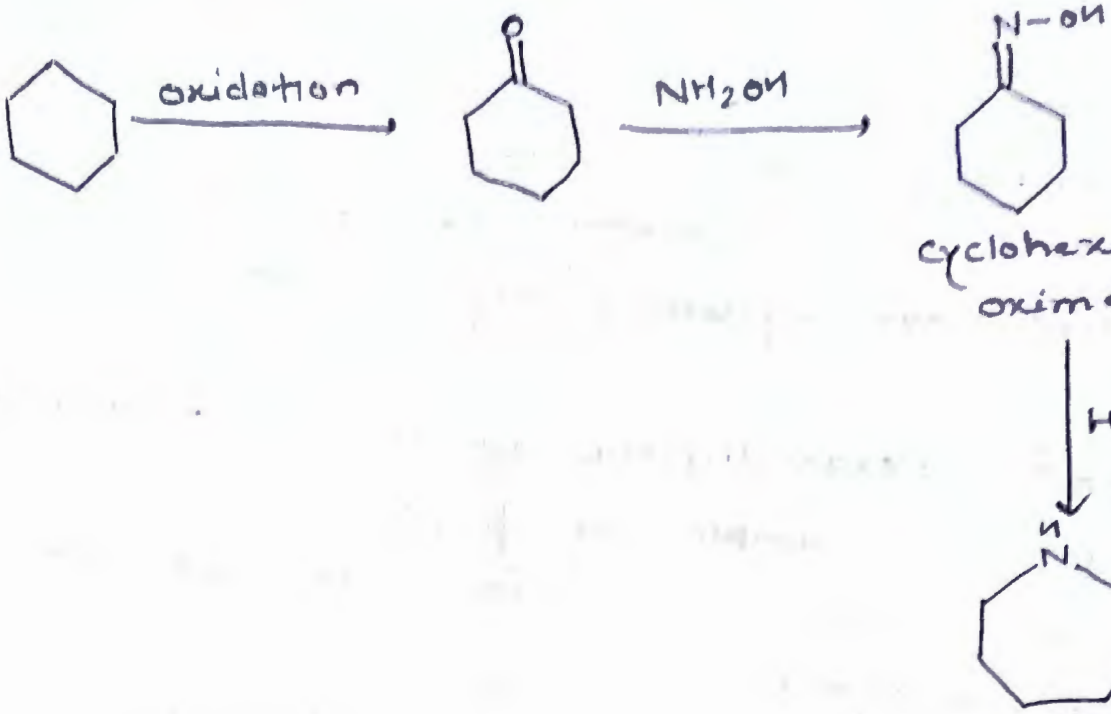
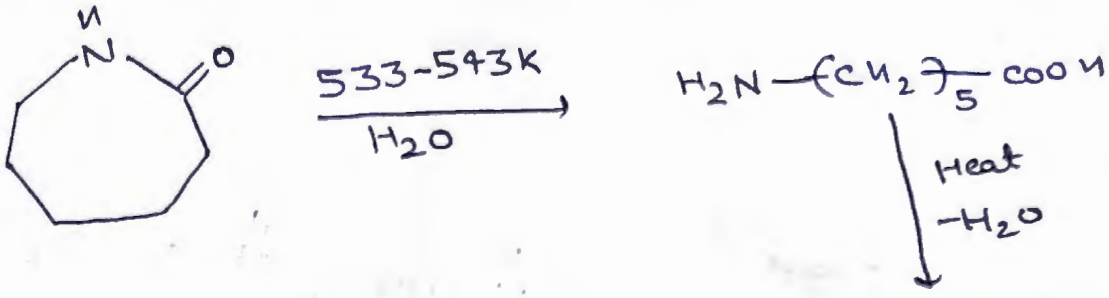
Nylon-6

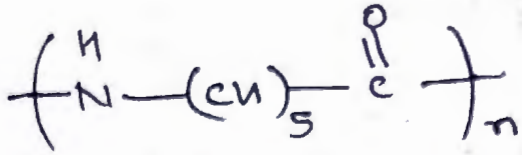
Monomer: caprolactum:

Obtaining of caprolactum-



caprolactum on heating with tracer of H_2O, gives





used in manufacture of tyre

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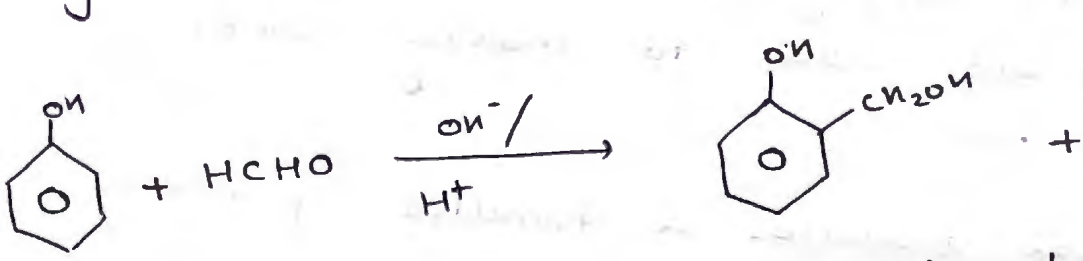
Phenol-formaldehyde resins -

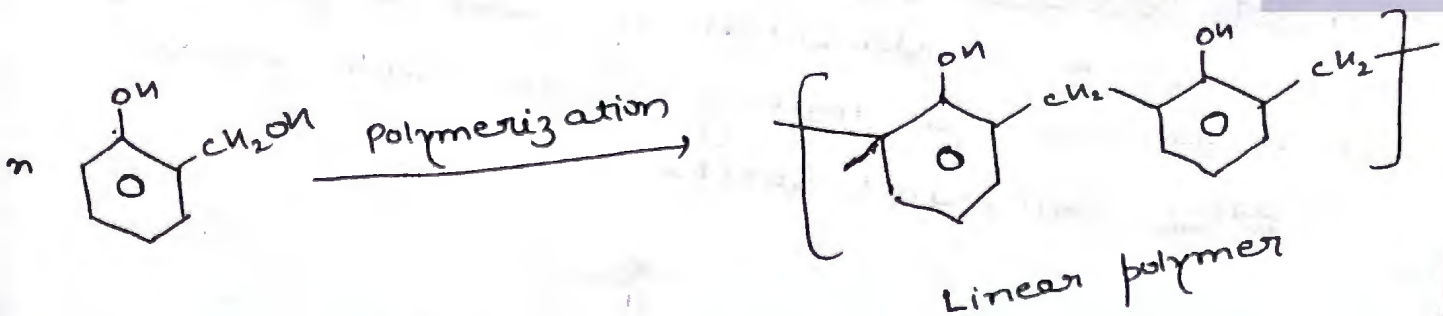
- It is a condensation polymer obtained from phenol & formaldehyde
- These reactant or monomer react with each other having methylene bridges either at ortho or at para position or both at ortho/para position with respect to phenolic group.

The initial product is a linear product called Novolac, which is also used in paints on further heating with formaldehyde it undergoes cross linking to form infusible solid called bakelite



o-Hydroxibenzyl alcohol

p-hydroxy benzyl alcohol.



Linear polymer

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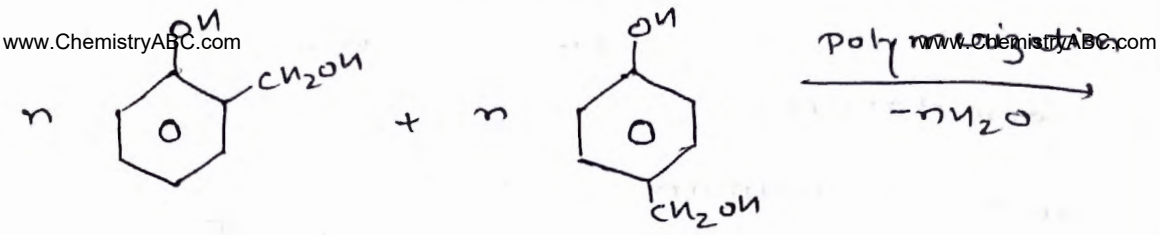
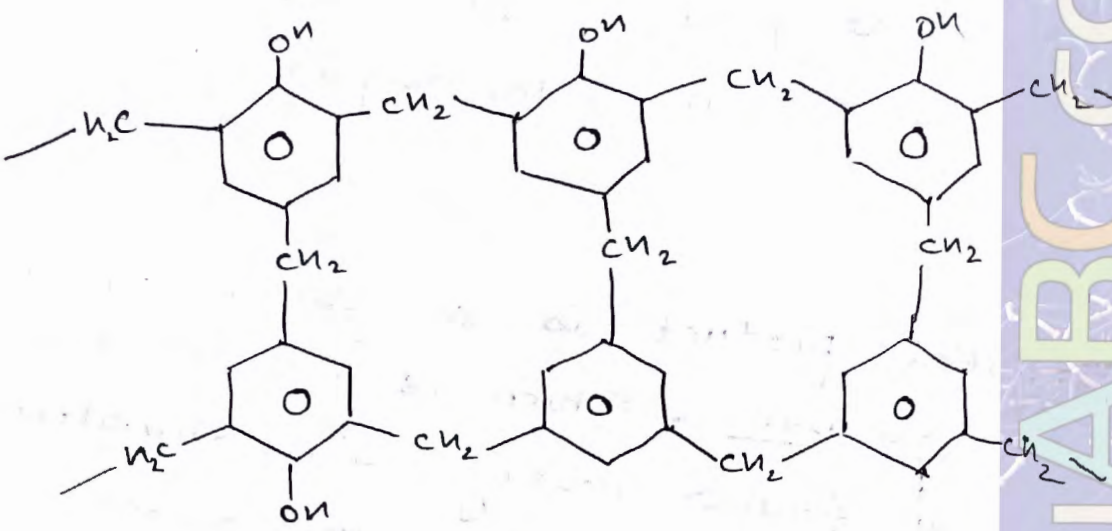


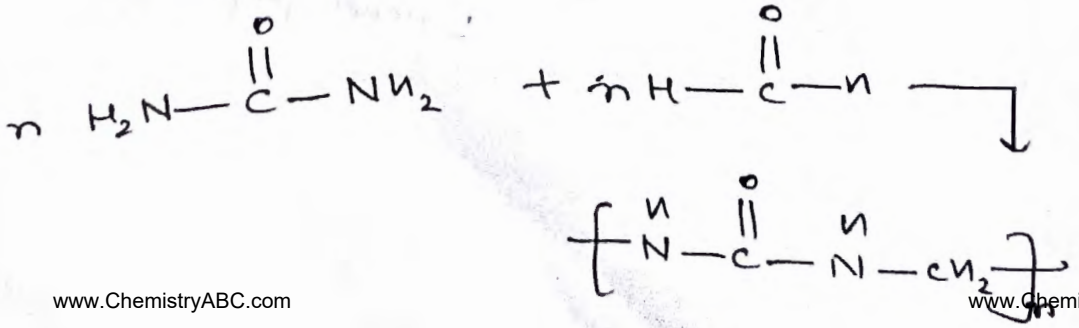


→ HDPE → Give gives hard baekelites which are used to making comb, fountain pen.

- electrical switches & handles of various utensils.

Urea formaldehyde resin -

- It is a condensation of urea & formaldehyde
- It is used for making unbreakable cups, plates, laminated sheets.



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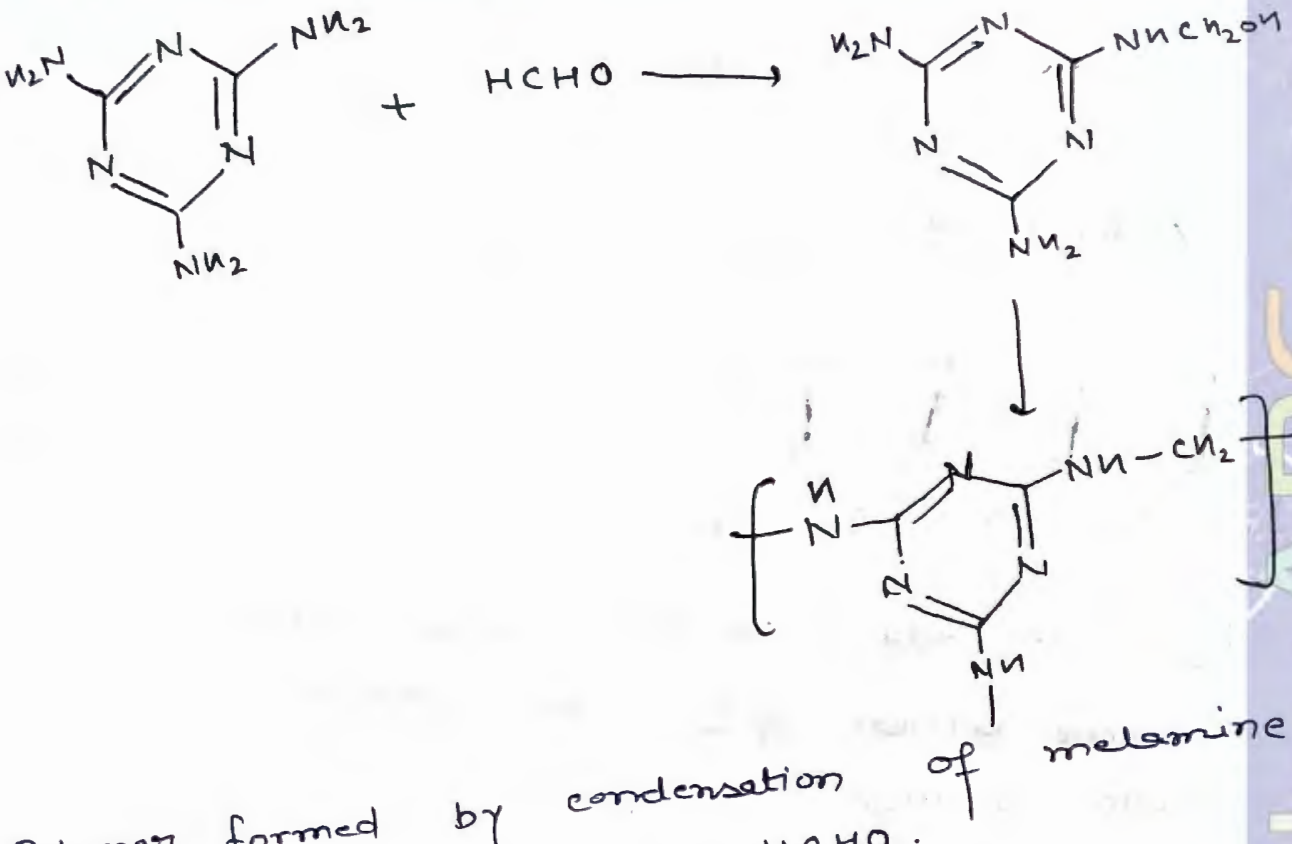
Melamine formaldehyde resin -



Polymer formed by condensation of melamine (Heterocyclic triamine) with HCHO.

Used in making crockery.

- Making cup, plates

Q. Buna-S is obtained from polymerization of - - - -

Q. which to make bullet proofs

(i) PMMA

(ii)

(iii)

(iv) Kevlar

Q. chain growth - polypropylene.

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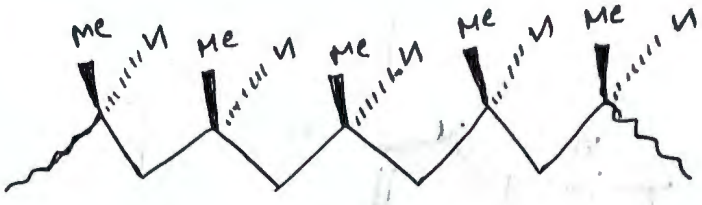
Classification on the basis of Assymetric carbon atom

(1) Isotactic →



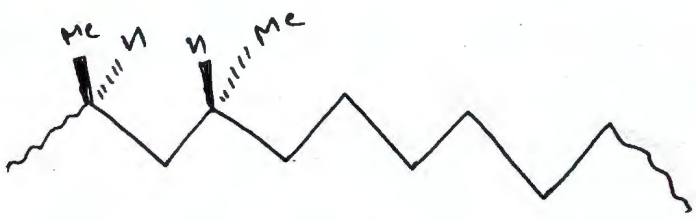
Polymer in which all the carbon atom have same either D/L are called isotactic polymer.

e.g. Isotactic polypropylene

$$CH_3-\underset{H}{\overset{|}{C}}=CH_2$$

All the methyl group are located on one side & Hydrogen on other side.

(2) Atactic →



Having random sequence of configuration.

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) Syndiotactic -

Having regular sequence of configuration.

he substituent group lie alternatively above & below the plaine of main chain

Identify the isotactic polypropylene from the following

(a)

(b)

(c)

(d)

following polymeric structure is generally ferred as -

(a) Isotactic
(b) Syndiotactic
(c) atactic
(d) Tactic

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Root mean Square end to end distance of polymer chain -

of a one dimensional flexible chain is given by $\sqrt{nl^2}$

$$\sqrt{\bar{r}^2} = \sqrt{nl^2}$$

n = no of segment of the polymer chain.

l = length of each segment or bond length. (C-C)

$$n = C_n - 1$$

↓ no of monomer unit.

Q- Average end to end distance of a random coil polymer of 10^{+6} monomer in units of segment length is

(a) 10^{+6} (b) 10^{-5} (c) 10^{4} (d) 10^{3}

$n = 10^{-6} - 1$

$n = 10^{6} - 1$

$= 10^{6}$

$(10^{-6})^2 (1 - 10^{-6})$

10^{-12}

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$\sqrt{r^2} = \sqrt{10^6 l^2}$

$\sqrt{r^2} = 10^3 l$

Q. What is the end to end distance of a polymer chain $C_{20}H_{42}$. Given that C-C bond length is 154 pm

Solution

154×10^{-12} m

$n = 19$

$\sqrt{r^2} = \sqrt{19 \times 154 \times 10^{-12}}$

$= \sqrt{19} \times 154$

$= 4.35 \times 154$

$= 671$ pm

Q. A polymer chain has 500 segments the length of each segment is 1.2 nm If the polymer chain is totally flexible when dissolve in water. What would be the rms .... (TIFR 2011)

Ans $n = 500$

$l = 1.2$

$\sqrt{r^2} = \sqrt{nl^2}$

$\sqrt{r^2} = \sqrt{500 \times 1.2 \times 1.2}$

$1.2 \times \sqrt{500}$

$= 1.2 \times 22.360$

26.832

(a) 600 nm (b) 417 nm (c) 27 nm (d) 300 nm

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Types of Molar mass ⇒

① No average molar mass–

is obtained by carrying out the summation over the fraction of molecule X by their corresponding molar mass. (multiplied)

It is represent by

$$\overline{M_n} = \sum f_i M_i$$

$$f_i = \frac{n \text{ (no)}}{N \text{ (Total no)}}$$

M_i = particular ka mass.

The subscript n stands for the number & the bar over the symbol M_n represent the average.

f_i is given by $= \frac{N_i}{N_{total}}$

N_i = no of molecule having mass M_i

N_{total} total no of molecule

$$N_{total} = \sum N_i$$

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$$\overline{M_n} = \frac{\sum N_i M_i}{N_{total}}$$

* 3 types of molecules containing no of molecule n_1, n_2 & n_3 & their corresponding molar mass are m_1 m_2 m_3 then $\overline{M_n}$

$$\overline{M_n} = \frac{N_1M_1 + N_2M_2 + N_3M_3}{N_1 + N_2 + N_3}$$

The method used to determine the no average molar mass is osmometry (osmotic pressure method).

(a)- **Osmotic pressure for the measurement of molar mass**

$$\frac{\pi}{CRT} = \frac{1}{\overline{M_n}} + BC$$, virial equation.

BC → second virial coefficient

or

$$\frac{\pi}{c} = \frac{RT}{\overline{M_n}} + BC \cdot RT$$

c = Polymer concentration

$\frac{\pi}{c}$ = reduce osmotic pressure.

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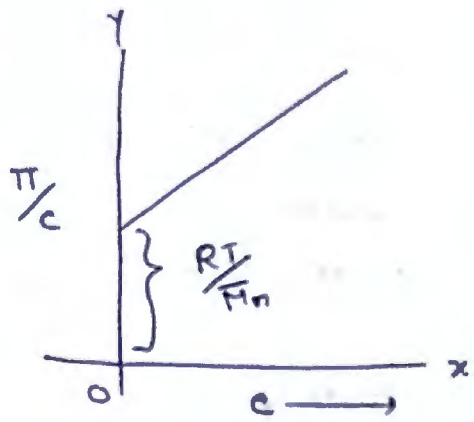
On plotting a graph between

$\frac{\pi}{c}$ vs c



Q. The ostomic pressure (π) of polymeric sample @ different concentration (c) was measured at T(K). A plot of π/c versus c gave a str B line with slope (m) & intercept c'. The no average mol. wB of the polymer is (R = gas constant).

Solution -

$$\frac{\pi}{c} = \frac{1}{\bar{M}_n} + Bc$$

(a) RT/c'

(b) c'/RT

(c) RT

(d) mRT

$$c' = \frac{RT}{\bar{M}_n}$$

$$\Rightarrow \bar{M}_n = \frac{RT}{c'}$$

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Q. A plot of osmotic pressure against concentration (g/L) of a polymer is constructed. The slope of graph

(a) ↑ with ↑ in Temperature

(b) ↑ with ↑ in molar mass of polymer.

(c) ↑ with ↓ in conc of polymer.

(d) ↓ with ↑ in temperature.

Q→

(2) Mass average / Weight average →

$(\bar{M}_m)$ $(\bar{M}_w)$

molar mass

The mass average is obtained by carrying out the summation over the mass fraction X by corresponding molar mass

$$W_i = \frac{m_i}{M_{total}}$$

W_i ← mass fraction

$$\overline{M_w} = \bar{M}_m = \sum W_i M_i$$

$$\overline{M_w} = \frac{\sum m_i M_i}{m_{total}}$$

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m_i = mass of the polymer molecule having mass M_i

M_{total} = total mass of the sample of the polymer.

which is given by

$$\overline{M_W} = \frac{\sum m_i M_i}{M_{total}}$$

$$= \frac{\sum \frac{m_i}{M_i} \times M_i \times M_i}{\sum m_i \times \frac{M_i}{M_i}}$$

$$= \frac{\sum N_i M_i^2}{\sum N_i M_i}$$

Molecule

$$\frac{N_i}{N_A} = \frac{m_i}{M_i}$$

N_A → Avogadro

$$N_i = N_A \times \frac{m_i}{M_i}$$

$\frac{N_i}{N_A}$ = mole

The method used for determination of mass average or weight average
Light Scattering method

3) Z average molar mass

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$$\overline{M}_z = \frac{\sum N_i M_i^3}{\sum N_i M_i^2}$$

The method used for determing Z average is molar mass is sedimentation method

4) Viscosity Average molar mass

$$\overline{M}_v = \left(\frac{\sum N_i M_i^{a+1}}{\sum N_i M_i} \right)^{1/a}$$

The value of a lies in the range

$0.5 < a < 1.0$

when $a = 1$

$\overline{M}_v = \overline{M}_n$

The constant a is known as Mark- Houwink eq exponent.

Method used - Intrinsic viscosity method.

$[\eta] =$

$[\eta]$ = Intrinsic viscosity

η_r = c = concentration of polymeric solution

η = viscosity of solution

η_0 = viscosity of pure solvent

$$[\eta] = \lim_{c \to 0} \frac{1}{c_2} \left[\frac{\eta}{\eta_0} - 1 \right]$$

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Mark Houwink equation –

The intrinsic viscosity of polymeric solution is found to increase, with increase in average molar mass of the polymer, this dependance is expressed as,

$$[\eta] = K \cdot \bar{M}_v^{a} \longrightarrow (1)$$

Mark Houwink eq.

K & a → are known as Mark Houwink eq.

Q→ Using standard equation $[\eta] = K \cdot \bar{M}_v^{a}$ for a solution of polymer & any information from the graph, to identify viscosity average molar mass ($\bar{M}_v$)

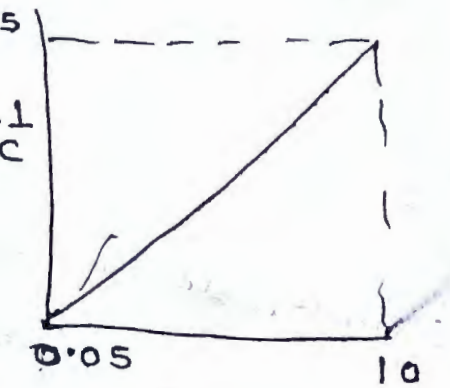
[Given that $a = 0.5$, $K = 5 \times 10^{-5}$ dl g^{-1}]

(a) 10^3 g mol^{-1}

(b) 10^4 g mol^{-1}

(c) 10^5 g mol^{-1}

(d) 10^6 g mol^{-1}



[June, 2015]

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We analyse

$$[\eta] = 0.05$$

$$0.05 = 5\times10^{-5}\ [\bar{M}_v]^{0.5}$$

$$[\bar{M}_v]^{\frac{1}{2}} = \frac{0.05}{5\times10^{-5}} = \frac{5\times10^{-2}}{5\times10^{-5}} = 10^{-2+5}$$

$$= 10^3$$

$$[M_v] = 10^6$$

Polydispersity index (PDI) →

* $\bar{M}_z \geq \bar{M}_w \geq \bar{M}_v > \bar{M}_n$ (or =)

The ratio of

$$P.D.I. = \frac{\bar{M}_m}{\bar{M}_n}$$

The ratio of $\bar{M}_m / \bar{M}_n$

$\because \bar{M}_m > \bar{M}_n$

$\Rightarrow$ P.D.I is > 1

if in any case $\bar{M}_w$ $\bar{M}_m = \bar{M}_n$

$\Rightarrow$ P.D.I. = 1 (Monodisperse)

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Q- for a polydisperse macromolecular colloid osmometry gives,

(a) weight - average

(b) Number- average

(c) both weight average & number average

(d) viscosity average molecular wt.

Q- There are several types of mean molar masses of polymer & they are dependent on experimental method

① osmometry

② Light scattering

③ Sedimentation

Correct relation between mean molar masses & experimental method is-

(a) $\bar{M}_n \Leftrightarrow (3)$, $\bar{M}_w \Leftrightarrow (2)$, $\bar{M}_z \Leftrightarrow (1)$

(b) $\bar{M}_n \Leftrightarrow (2)$, $\bar{M}_w \Leftrightarrow (3)$, $\bar{M}_z \Leftrightarrow (1)$

(c) $\bar{M}_n \Leftrightarrow (1)$, $\bar{M}_w \Leftrightarrow (2)$, $\bar{M}_z \Leftrightarrow (3)$

(d) $\bar{M}_n \Leftrightarrow 1$ $\bar{M}_w \Leftrightarrow 3$ $\bar{M}_z \Leftrightarrow (2)$

Q- The no average molar mass ($\bar{M}_n$) & wt average molar mass ($\bar{M}_w$) of a polymer are obtained respectively

(a) osmometry & light scattering

(b) Osmometry viscosity measurement

(c) Light scattering & sedimentation m

(d) Viscosity & light scattering

2

Q- A polymer sample has the following composition

No of molecules	Molecular wt
10	1000
50	2000
40	4000

The P.D.I. of the polymer is

(a) $\frac{85000}{27}$

(b) $\frac{85}{81}$

(c) $\frac{850}{729}$

(d) $\frac{729}{850}$

$$\bar{M}_n = \frac{10\times1000 + 50\times2000 + 40\times1000}{100}$$

$$\bar{M}_n = \frac{10,000 + 10,000 + 16,000}{100}$$

$$\bar{M}_n = \frac{270000}{100} = 2700$$

$$\bar{M}_w = \frac{\sum N_i M_i^2}{\sum N_i M_i}$$

$$= \frac{10\times10^6 + 50\times4\times10^6 + 16\times10^6}{270000}$$

$$= \frac{850\times10^6}{270000} = \frac{850\times10^2}{27}$$

$$P.D.I = \frac{\frac{850\times10^2}{27}}{2700} = \frac{850}{729}$$

The ratio of

Q. The ratio of mean molar masses of a given polymer sample has determined by light scattering, sedimentation, osmotic pressure, measurem

(a) 112

(b) 212

(c) 121

(d) 221

Q. Which of the following method yield a rate average molecular wt m of polymer.

(a) vapour pressure osmometry

(b) membrane "

(c) Light Scattering

(d) Mass spectrometry

Q- The molar masses of mono disperse & poly disperse polymer obey respectively the condition-

$\bar{M}_v$ = No average molecular weight

$\bar{M}_w$ = weight " " "

(a) $\bar{M}_n > \bar{M}_w$ & $\bar{M}_n < \bar{M}_w$

(b) $\bar{M}_n = \bar{M}_w$ & $\bar{M}_n < \bar{M}_w$

(c) $\bar{M}_n$ *

(d)

Q- The mark ~~Hou~~ Houwink equation $[\eta] = KM^a$ is used for determination of

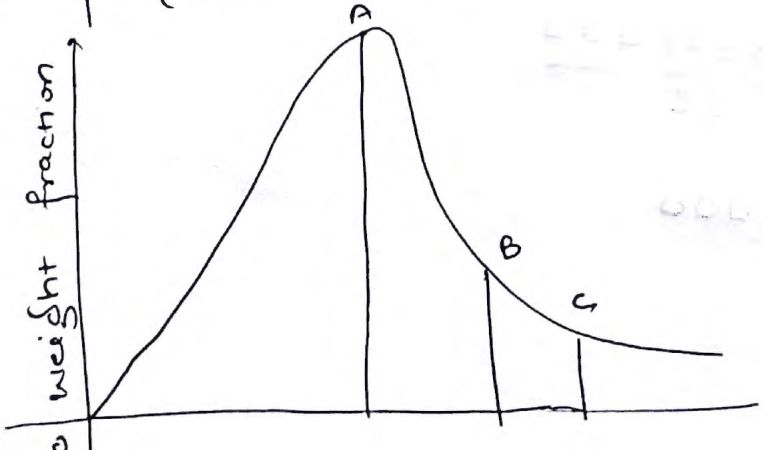
(a) No average

(b)

(c) viscosity average molar mass (✓)

(d)

Q- The distribution of molar mass in typical polymer sample



(a) $\bar{M}_w$, $\bar{M}_v$ & $\bar{M}_n$ respectively

(b) $\bar{M}_n$, $\bar{M}_v$ & $\bar{M}_w$ "

(c) $\bar{M}_v$, $\bar{M}_w$ & $\bar{M}_n$ "

(d) $\bar{M}_n$, $\bar{M}_w$ & $\bar{M}_v$ "

Q. A polydisperse polymer has 10 molecule of molar mass 20,000 $g\,mol^{-1}$ & fifteen molecules of molar mass 10,000 $g\,mol^{-1}$

The no average molar mass in $g\,mol^{-1}$

(a) 13,000

(b) 14,000

(c) 15,000

(d) 16,000

$$\bar{M}_n = \frac{N_1M_1 + N_2M_2}{N_1 + N_2}$$

$$\frac{10 \times 20000 + 15 \times 10,000}{25}$$

$$= \frac{3,50,000}{25}$$

$$= 14,000$$

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Q for a monodisperse polymer $\bar{M}_n$ & $\bar{M}_w$ are related acc to

(a) $\bar{M}_w < \bar{M}_n$

(b) $\bar{M}_w = \bar{M}_n$

(c) $\bar{M}_w > \bar{M}_n$

(d) $\bar{M}_w < \log \bar{M}_n$

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53. The correct expression for the product $((\bar{M}_n \cdot \bar{M}_w))$ [$\bar{M}_n$ & $\bar{M}_w$ are the number average & weight average molar masses, respectively, of a polymer] is Dec-2015

(1). $N^{-1} \sum_i N_i M_i$

(2). $N^{-1} \Sigma_i N_i M_i^2$

(3). $N / \sum_i N_i M_i$

(4). $N / \sum_i N M_i^2$

$$\bar{M}_n = \frac{\Sigma N_i M_i}{N} \rightarrow (2)$$

$$\bar{M}_w = \frac{\Sigma m_i M_i}{M_{total}}$$

(or)

$$= \frac{\Sigma N_i M_i^2}{\Sigma N_i M_i} \rightarrow (1)$$

(1) × (2)

$$\frac{\cancel{\Sigma N_i M_i}}{N} \times \frac{\Sigma N_i M_i^2}{\cancel{\Sigma N_i M_i}}$$

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