Seth Campbell
Senior Biochemistry Major

What is a Dendrimer?

Abstract: Description, terminology, properties, and applications of dendrimers are presented in this paper.

Description

A dendrimer is a spherical, highly branched synthetic polymer with functional groups all facing away from the core just like the suction cup ball as shown in **Figure 1**. They are synthesized beginning with a core molecule such as diaminobutane (DAB) or cystamine (CYST), and adding branching and functional groups to the outside. The outer functional groups are called “surface groups” and a wide variety can be synthesized. Surface groups can be categorized by charge: cationic – amine; neutral – hydroxyl and pyrrolidinone, anion – carboxylic acid. Every time the synthetic process is repeated, larger dendrimers are created, and this is called a “generation” and described as Generation 1 (G1), Generation 2 (G2), Generation 3 (G3), etc. **Figure 2** shows a polyamidoamine (PAMAM) dendrimer with a DAB core with eight primary amine surface groups. PAMAM dendrimers approximately double their molecule weight and number of surface groups for every generation of growth. **Figure 3**, at the end of this document, illustrates PAMAM DAB-Core Dendrimers from G0 through G3 with a description of the molecular weights and number of surface group. A G5 PAMAM dendrimer is highly structured sphere with tight spacing between the surface groups. PAMAM dendrimers are synthesized in two basic steps using ethylenediamine and methylacrylate monomers to create a single generation dendrimer, and these steps are repeated to grow the dendrimer to the next generation. This multistep process is solvent based and can be carried out using standard chemistry laboratory equipment.

Figure 1: Suction ball is a good representation of a dendrimer.

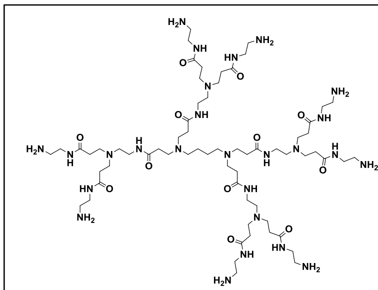


Figure 2: Generation 1 (G1) PAMAM dendrimer with eight surface groups.

Properties

Dendrimer’s unusual properties have been referred to as “dendritic effects” which result from the dendrimer size and the spherical arrangement of the surface groups.[1] Some of these effects can be shown by comparing dendrimers to chemically similar linear polymers. Dendrimer have a lower intrisic viscosity then their linear polymer counterparts. Dendrimer intrinsic viscosity increases until the dendrimer reaches the fourth generation where the viscosity starts to decline. Linear polymers on the other hand get more and more viscous as the molecular weight increases. This unusual viscosity effect along with the numerous surface groups has a profound influence on the solubility of dendrimers. Dendrimers can form solutions at higher concentrations, some as high as 40 to 50 wt%, which greatly exceeds the solubility of most linear polymers of similar molecular weight and chemistry.[2] Another difference between dendrimers and their linear counterparts are their general reactivity. Because the dendrimer's active groups are all facing outward, they have more available active sites than linear polymers do. As with a suction cup ball, many functional groups can interact with a surface or another molecule which multiplies the number of connections, and this extra stickiness is referred to as "polyvalency". Polyvalent interactions happen when multiple ligands on one molecule bind simultaneously to multiple receptors.[3]

Dendrimers can be chemically modified to dissolve in a variety of solvents. If the surface groups are all hydrophobic, e.g. octyl group, then the dendrimer will only be soluble in organic solvents such as toluene or dichloromethane. On the other hand if the surface groups are hydrophilic, such as amines or hydroxyl groups, then the dendrimer will be highly soluble in water. Solution concentrations as high as 40 to 50 wt% have been made without much change to the viscosity of the entire solution. This lack of change in viscosity in response to changing concentration is another characteristic property of dendrimers.

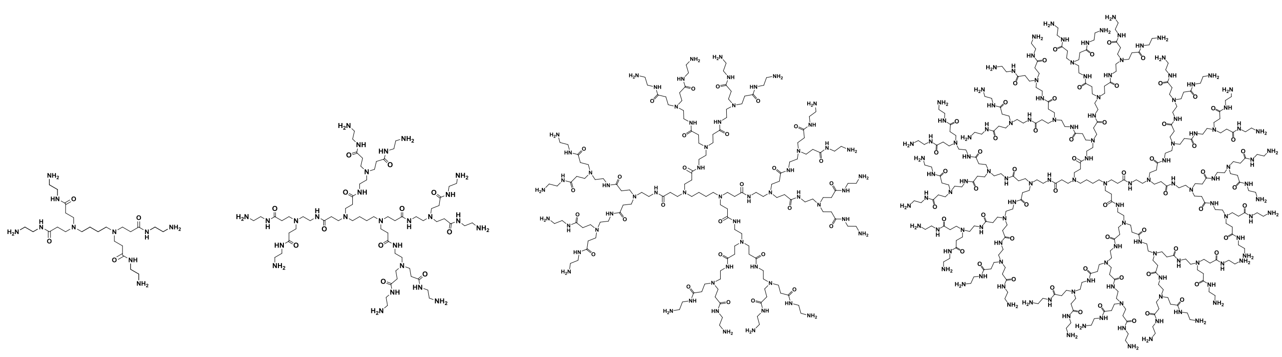
Another dendritic effect is the "container property" which allows dendrimers to encapsulate pharmaceuticals, cosmetic ingredients, metals catalysts, and a variety of small molecules[4]. "As nanocarriers, dendrimers have the versatility to allow conjugation, complexation, and encapsulation to a variety of other molecules or biomolecules. The functional groups on the periphery of the dendrimer act as highly accessible handles for drug or other functional group attachments"[5]. The encapsulation process can be performed using a variety of loading, mixing, and separation techniques and these dendrimer-cargo complexes can be tailored to unload using pH, light, concentration gradients, and other chemical and biochemical means. Aspirin was one of the first molecules to be proven to be encapsulated within the dendrimer structure.

Applications

Researchers are studying the ability of dendrimers to encapsulate molecules to carry medicines, such as very toxic cancer drugs, directly to cancerous cells without harming the normal cells[6]. When the dendrimer reaches the cancer cells then the reaction can take place to release the encapsulated drug. This localized release of drugs can greatly reduce the damaging side effects to the cancer patient's body. Dendrimers can also be used to act as a time release agent for drugs and as vectors to carry genetic material into a cell's nucleus. Dendrimers have been used as a catalyst since their creation. "The dendritic architecture leads to an improvement in the catalytic performance…such effects have been observed for metallic and non-metallic catalytic systems".[7] Dendrimers can also be used as an excipient to improve the solubility of poorly soluble materials.

Summary

Dendrimers are a highly branch, spherical, synthetic polymer that have many properties that make them different from their linear or slightly branched counterparts including intrinsic viscosity, solubility, polyvalency, and reactivity. These properties allow them to be used for special applications such as a nanocontainer for medicine, a vector for genetic material, solubility enhancer, or as a catalyst for chemical reactions.



PAMAM G0
Core: DAB
Surface: Amine
#Groups: 4
MW: 545

PAMAM G1
Core: DAB
Surface: Amine
#Groups: 8
MW: 1458

PAMAM G2
Core: DAB
Surface: Amine
#Groups: 16
MW: 3284

PAMAM G3
Core: DAB
Surface: Amine
#Groups: 32
MW: 6937

Figure 3: PAMAM dendrimers with DAB (diaminobutane) cores and primary amine surface groups. Sizes are typically available up to G6.

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