Polymer Activity from the:

What Is A Polymer?

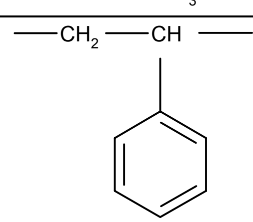
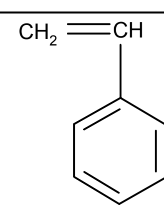
Grades: 6-8 and 9-12

Science Standards: Content Standard B: Physical Science; Content Standard E: Science and Technology

Background:

The most simple definition of a polymer is something made of many units. The units or “monomers” are small molecules that usually contain ten or less atoms in a row. Carbon and hydrogen are the most common atoms in monomers, but oxygen, nitrogen, chlorine, fluorine, silicon and sulfur may also be present. Think of a polymer as a chain in which the monomers are linked (polymerized) together to make a chain with at least 1000 atoms in a row. It is this feature of large size that gives polymers their special properties. Polymerization can be demonstrated by linking countless strips of construction paper together to make paper garlands or hooking together hundreds of paper clips or gum wrappers together to form extended chains.

Macromolecules or polymers are found in the human body, animals, plants, minerals and manufactured products. Substances like the following contain polymers: diamond, concrete, quartz, glass, nylon, plastics, DNA, tires, cotton, hair, bread, and paint. The macromolecule can have different end units, branches in the chain, variations in the sequence of the monomers, and different monomers repeated in the same chain which leads to the large number of manufactured polymers as well as all of the natural polymers. The table below shows just a few manufactured polymers that are made from the monomer on the right. The double bond in the monomer is broken or water (or some other molecule that can be boiled off) is eliminated in the polymerization process.

Polymer	Repeating Units	Monomer
Polyethylene	$—CH_2—CH_2—$	$CH_2{=}CH_2$
Poly(vinyl chloride)	$—CH_2—CH(Cl)—$	$CH_2{=}CH(Cl)$
Polypropylene	$—CH_2—CH(CH_3)—$	$CH_2{=}CH(CH_3)$
Polystyrene		

Natural polymers are in living animals and plants as building materials, storage substances and playing a role in biochemical reactions. Cellulose and lignin give structure to plants. Cellulose (starch or polysaccharide) is a macromolecule composed of individual sugar molecules (glucose) that are bonded together to give molecular weights in the millions. Cellulose is the basis for cotton and rayon fibers. Starch in plants stores glucose and, therefore, energy. Starch consists largely of two forms, one linear and one branched, both of which differ from cellulose because of the different way the glucose units are connected. Chitin is a nitrogen-containing polysaccharide found in shells, wings, and claws of animals. Proteins are polymers that are responsible for animal hair and fibers such as wool and silk. DNA is a polymer necessary for life processes in plants and animals. Natural rubber, from a tree, has isoprene (2-methyl-1,3-butadiene) as the monomer producing a very elastic product. Artificial rubbers are made from butadiene and other monomers and have many uses. Additives are necessary to change the physical properties for the manufacture of automobile tires. Inorganic polymers (not based on the carbon atom) include glass with its silicon-oxygen framework and other silicates as in granite and agate.

Think of how spaghetti noodles look on a plate. This is similar to how polymers can be arranged if they are amorphous. An amorphous arrangement of molecules has no 3-dimensional order in which the polymer chains arrange themselves. Amorphous polymers are transparent in the absence of additives. Transparency does not guarantee absence of crystallinity, it only indicates that there are no structures commensurate in size with visible light to cause the reflections that prevent transparency. This is an important characteristic for many applications such as Plexiglas®, headlights, and contact lenses. Controlling and quenching the polymerization process can result in transparent film from semi-crystalline polymers. Obviously not all polymers are transparent. The polymer chains in objects that are translucent and opaque are in a crystalline arrangement. By definition a crystalline arrangement has atoms, ions, or in this case, molecules in a distinct pattern. You generally think of crystalline structures in salt, gem stones, but not plastics. Just like quenching can decrease the crystalline fraction, cooling can be controlled to produce the degree of crystallinity desired. The higher degree the crystallinity, the less light can pass through the polymer. Therefore, translucent to opaqueness is directly affected by the crystallinity of the polymer. Increased crystallinity does not change the melting point of a polymer, but it does means that more energy is needed to cause the molecules to separate, melt and flow. Amorphous polymers, on the other hand, do not have melting points. They have glass transition temperatures below which they are intractable but above which flow is permitted. (See Unit Five on Plastics for more discussion on this topic.)

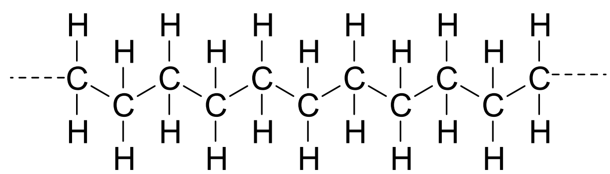
If the polymer has all the same monomers then it is said to be a homopolymer, like poly(vinyl chloride), polyethylene, and cellulose (-A-A-A-A-A-A-). A block copolymer would appear as, -A-A-A-A-A-A-B-B-B-B-B-B- and a random copolymer (rubber) contains a random distribution of monomer units like, -A-B-B-B-A-A-A-B-B-B-B-A-A-. Some polymers like nylon 66 or poly(ethylene terephthtalate) are made from two monomers, but both monomers must alternate if they are to produce a polymer so these types of polymers are also defined as homopolymers (-A-B-A-B-A-B-A-B-).

By manipulating factors on the molecular level that affect the final polymer produced, engineers continually are challenged to produce better- suited materials for countless old and new applications. Manufacturers and processors introduce various fillers, reinforcements, and additives into the base polymers expanding product possibilities. New developments in polymerization techniques are also leading to new and interesting types of polymers.

Teacher Demonstrations

Building Polyethylene Models Using An Addition Reaction

Give each student materials to make an ethane molecule (C_2H_6) from a model kit or with tooth picks and marshmallows. To form polyethylene, linking the monomers must be accomplished by an addition reaction. First the ethane molecule is dehyrogenated (removing H_2) to form ethylene or ethene (C_2H_4 or $H_2C=CH_2$). So students have to take off two hydrogen atoms and add a double bond between the carbons. Polyethylene is formed from the ethylene monomers by breaking the double bond of each ethylene and attaching the carbons to adjacent carbons on the next monomer. Start the reaction with the "initiation step" of a free radical (an unbonded electron hungry for electrons to form a bond). The teacher puts his/her hand on the double bond of one ethylene molecule. This breaks one of the bonds in the double bond. Now this ethylene is a larger free radical and is highly reactive. This can break apart another double bond and so on. The monomers join together as double bonds are broken in the "propagation steps". The "termination step" is when all the monomers are used in the chain or an impurity is introduced or it joins another chain that is forming. If the bond angles are correct, the polyethylene chain will be in a zigzag formation and not straight. Find the molecular weight of your class of polyethylene! (28 x #students)



This reaction continues to form single bonds since the energy in the chemical system is lowered as the chain grows. The single bonds in the chain are more stable than the double bonds of the monomers. The reaction is exothermic and occurs extremely fast (less than 0.1 second). Since your class polymer has no branches, it is very high density polyethylene and it will float on water. To reduce the density, the students need to rearrange themselves to make some side branches. The branches interfere with the packing ability of the polymer so the density decreases slightly.

Demonstration of Crystalline and Amorphous Properties

The amorphous portions of a polymer do not transmit plane polarized light. The crystalline or more ordered portions of a polymer do transmit polarized light or they are "optically active" and can rotate the plane of light that passes through. Stretching or stressing a plastic will increase the crystalline nature of the product. Polarized light is rotated as it passes through the plastic object giving rise to areas of varying colors at different polarized angles. Orient a sandwich of two polarizing films so that no light passes through when placed on an overhead projector. Place a sample of clear plastic like a picnic cutlery, polystyrene Petri dish, or plastic template for geometry between the two polarizers. Rotate the polarizers and see the colors change. The colors indicate that that portion of the object has the polymer chains in an ordered or crystalline arrangement. Take a strip from a baggie (one layer) and stretch it between two polarizing sheets. The colors observed are when the chains are being aligned into a more ordered arrangement. (Educational Innovations has a nice kit to show this idea and more: Educational Innovations, Inc., 151 River Road, Cos Cob, CT 06807 (203-629-6049) for the "Polarizing Filter Demo Kit").

Comparison of Alkanes (An illustration not a demonstration)

Physical behavior of the compounds in the alkane series is interesting and informative.

- Methane, CH_4, is a gas at room temperature and is used as fuel for Bunsen burners.
- Ethane, C_2H_6, is a gas at room tempature and is also flammable.
- Hexane, C_6H_{14}, is a very flammable liquid.
- Paraffin wax, C_{18} to C_{24} with appropriate hydrogens, is a solid with a relatively low melting point. People use it to make candles and often experience fires on the kitchen stove when it ignites. It can be cut with a knife and will break upon bending.
- Polyethylene, $CH_3\text{-}(CH_2CH_2)_n\text{-}CH_3$, (n=500 to 20,000) is a solid used in making baggies, milk jugs and food containers. Bread bags melt easily when touched by a hot toaster! Milk jugs can be bent and stretched. This polymer is much stronger than wax and it is resistant to impact and will not shatter easily.

Tearing Cellophane Tape and Rotating of Plane Polarized Light

Tear cellophane tape along its length and width. The tape tears smoothly and easily along its length because the chains of polymers are aligned in that direction. Tearing across its width is more difficult as one breaks the bonds of the long chains. A sharp edge is usually needed to start the width tear.

Numerous strips of (cheap) cellophane tape criss-crossed randomly over a piece of overhead transparency will demonstrate the rotation of plane polarized light. Orient a sandwich of two polarizing films so that no light passes through when placed on an overhead projector. Place the “taped” transparency between the two polarizers. Rotate the top polarizer and see the colors of the cellophane tape (the polymer chains) rotate the plane polarized light.

PopBeads to demonstrate how large a macromolecule can be are available from Cappels, 920 Elm Street, Cincinnati, OH 45202. The teacher discount is $ .72/package of 72. (513-621-0952)

Velcro can be used to demonstrate the strength of bonding in a polymer. Show how easy it is to pull open (shear) a short piece of Velcro that is overlapped about one inch. Then show how difficult it is to pull open a strip of Velcro that is overlapped about 10 inches.

Polystyrene (PS) cups that are clear and brittle will demonstrate the order of the polymer chains when you crack the cup to break it. It cracks in the direction of the chains that are parallel to the length of the cup. The cup is extruded in the lengthwise direction during manufacturing so the chains are parallel in that direction.

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