Unit 5
Polymers I

Slide Color Codes

All Lectures

Section Only

Required

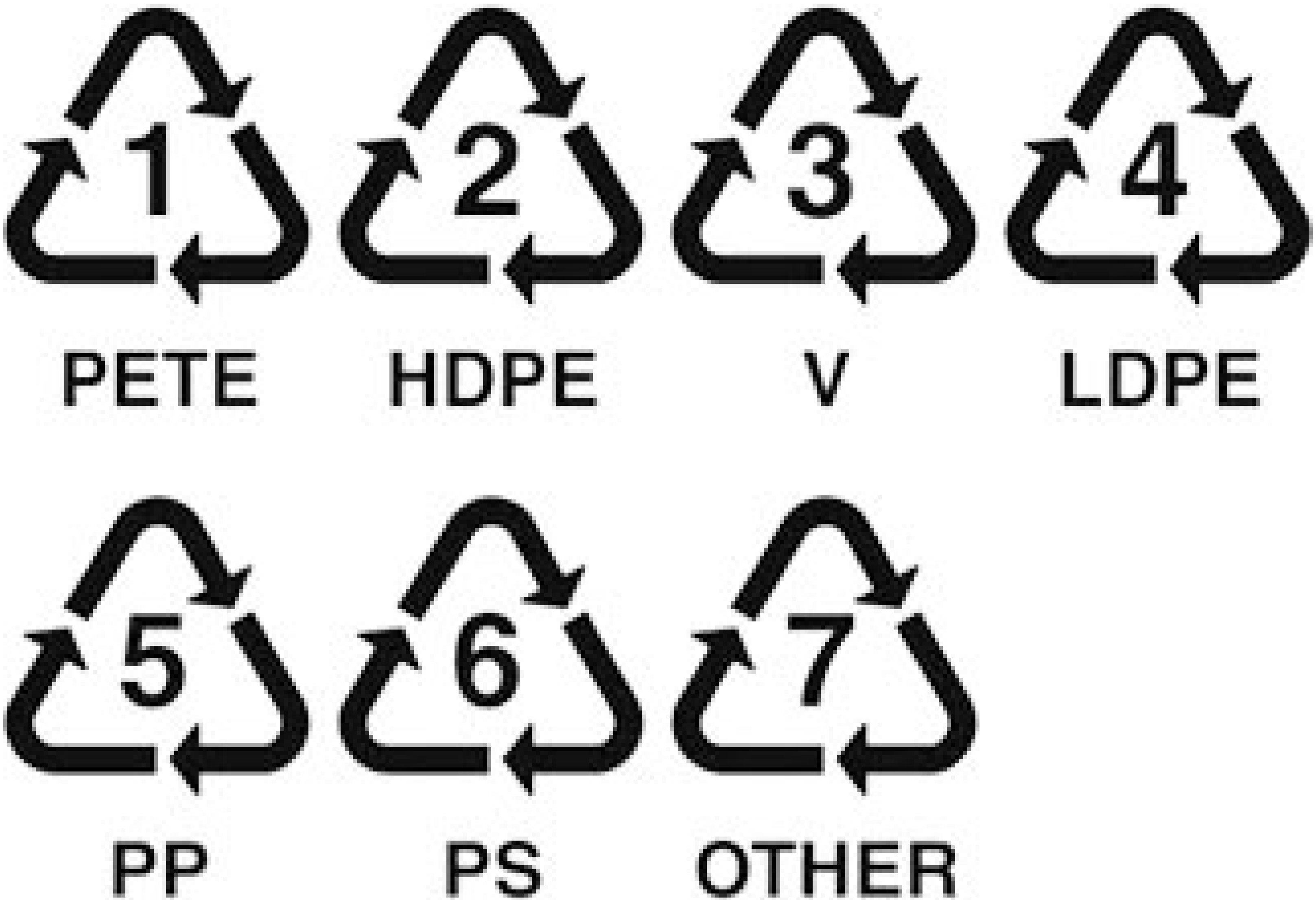
Required

OK to Skip

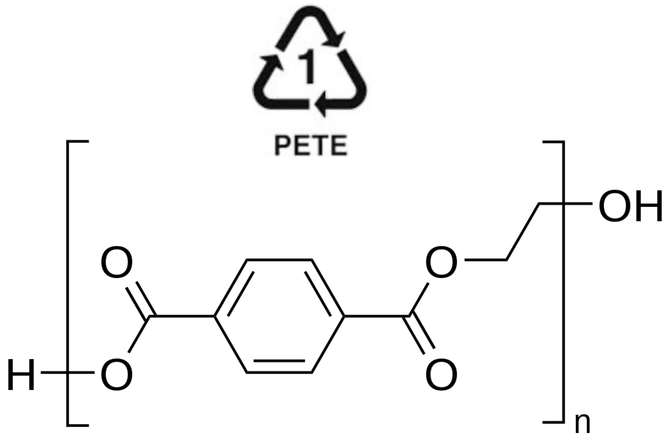
Useful

Not Examable

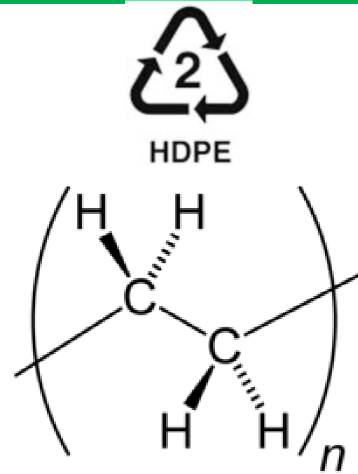
Plastic Recycle Numbers



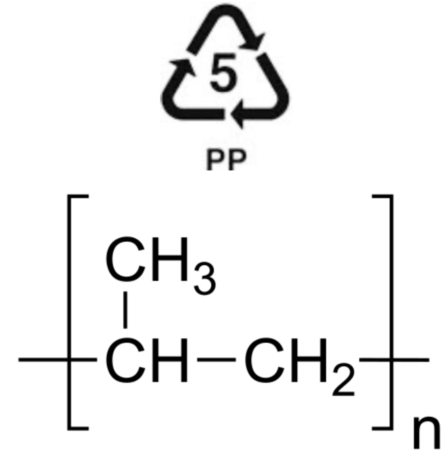
Manufactured Polymers



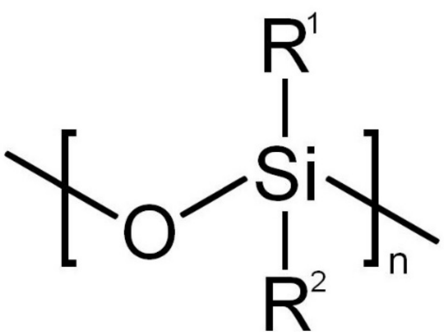
Polyethylene terephthalate
(PETE)



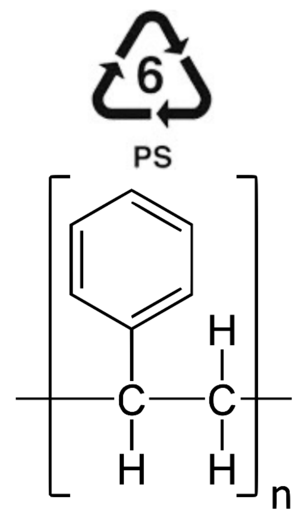
Polyethylene
(HDPE, LDPE)



Polypropylene
(PP)

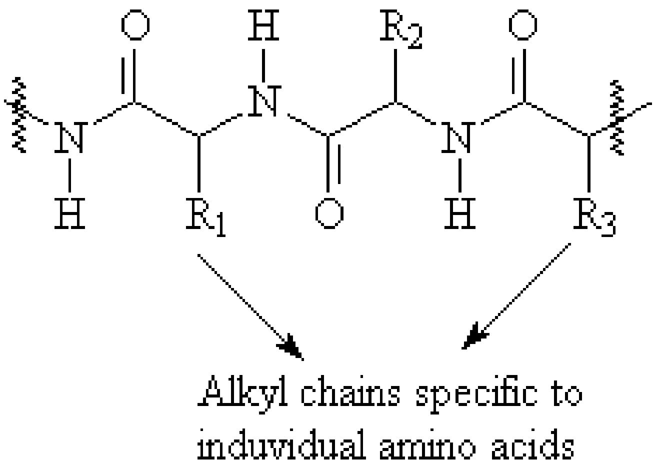


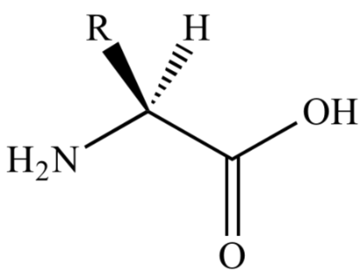
Silicones

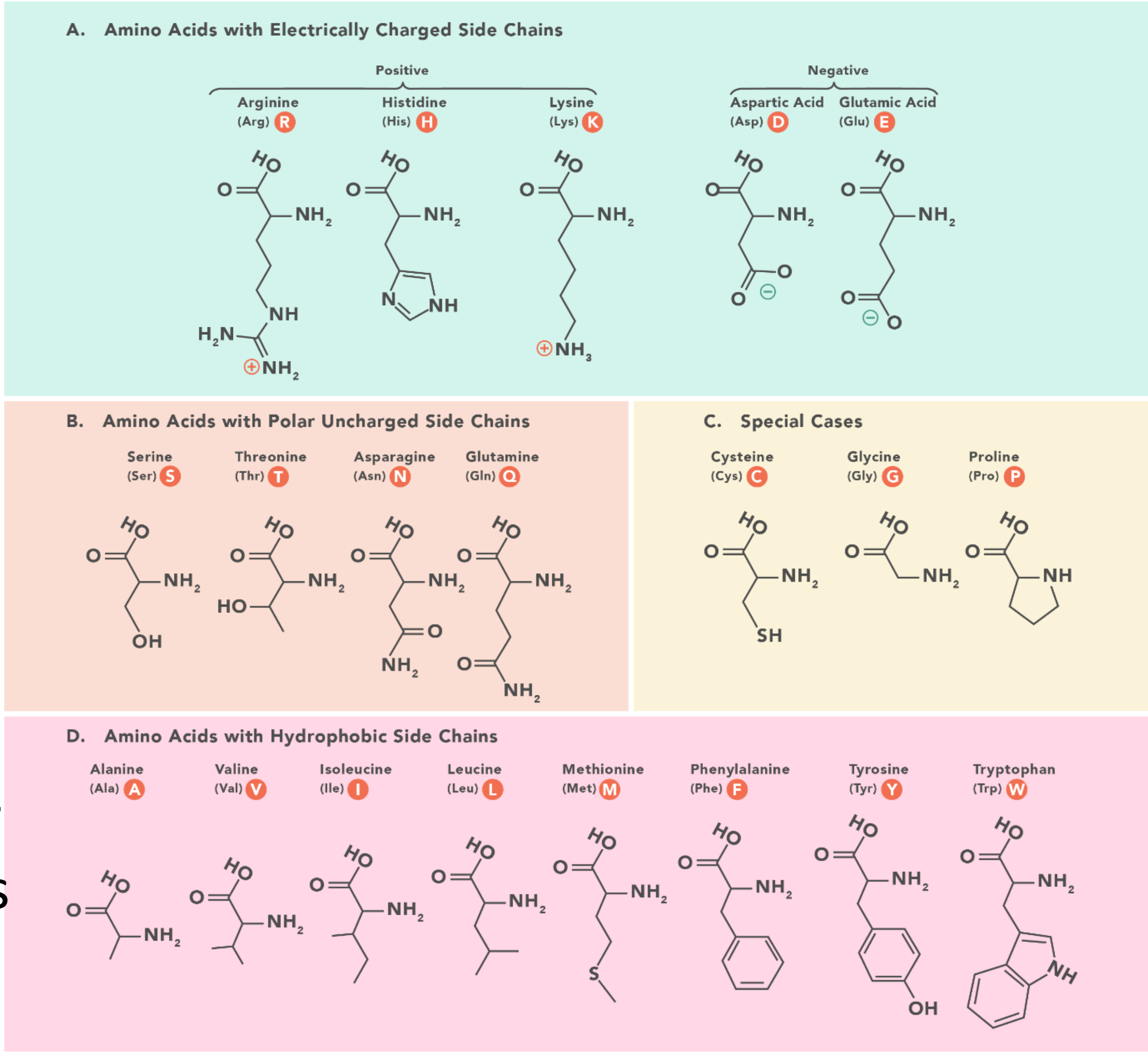


Polystyrene (PS)

Natural Polymers - Proteins



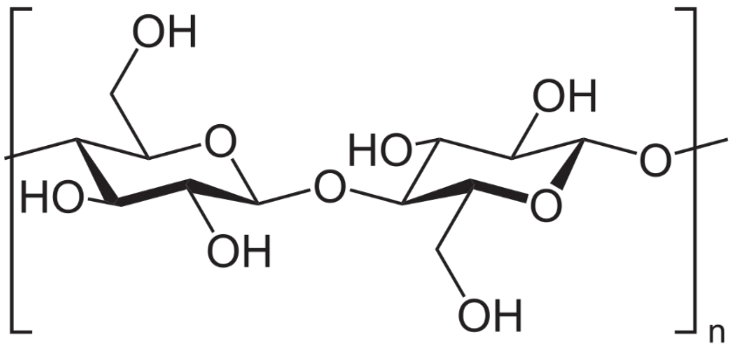




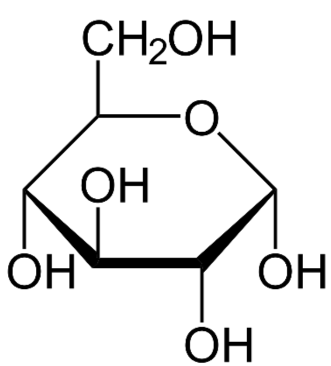
Amino acids are monomer building blocks for proteins

Natural Polymers

Cellulose

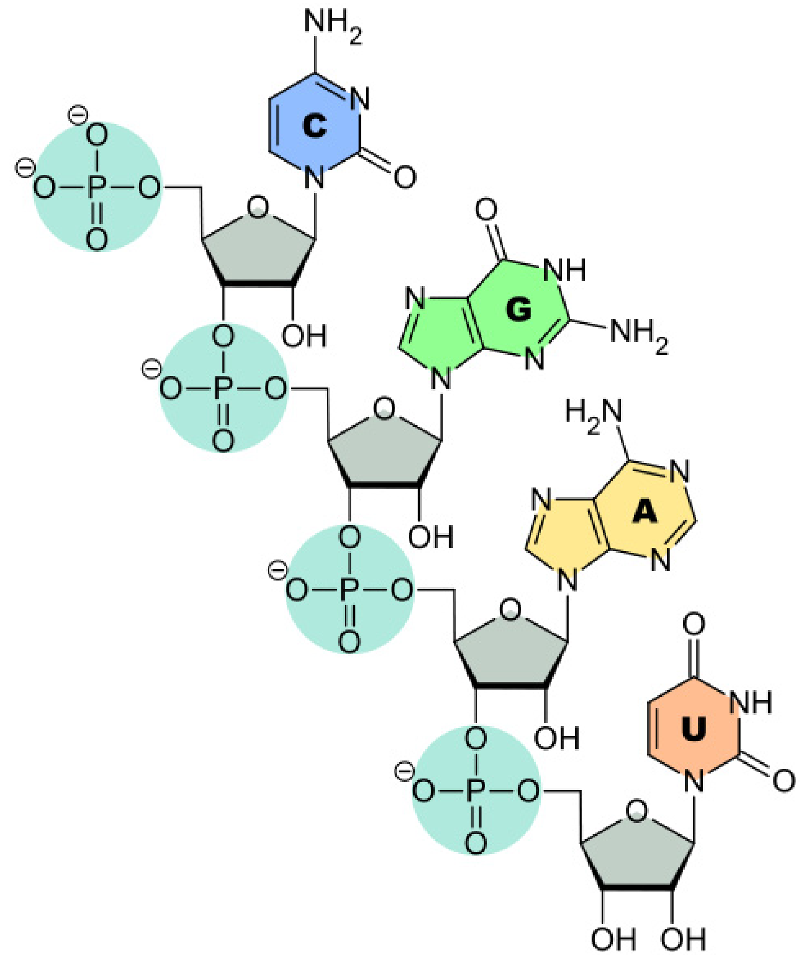


Glucose Monomer

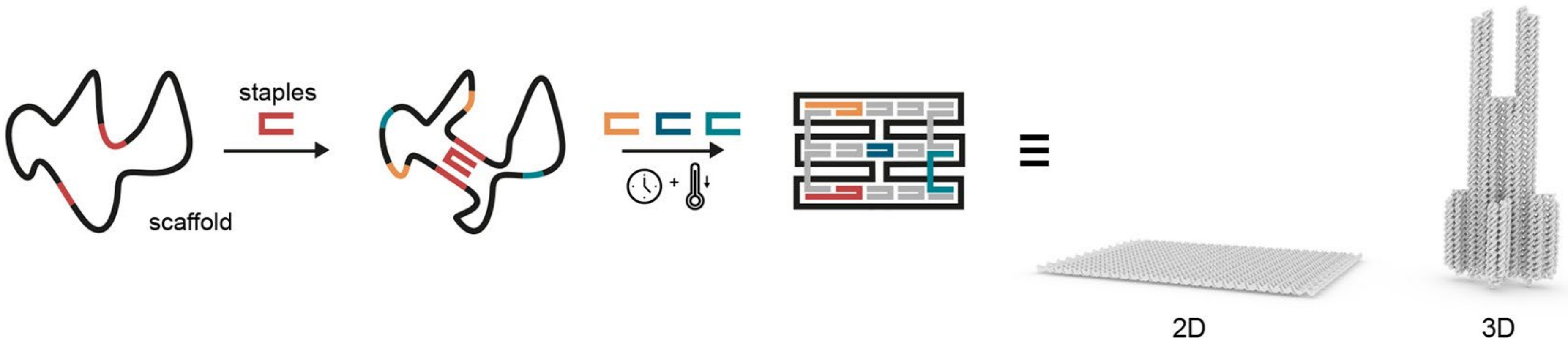


RNA (DNA)

Unique monomer sequencing

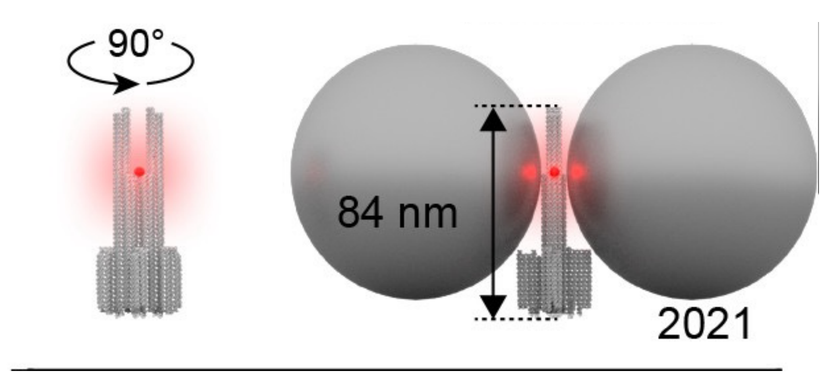


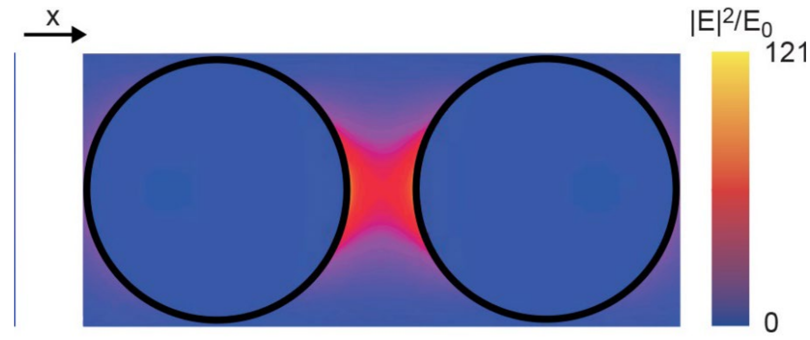
DNA Origami - structures from DNA



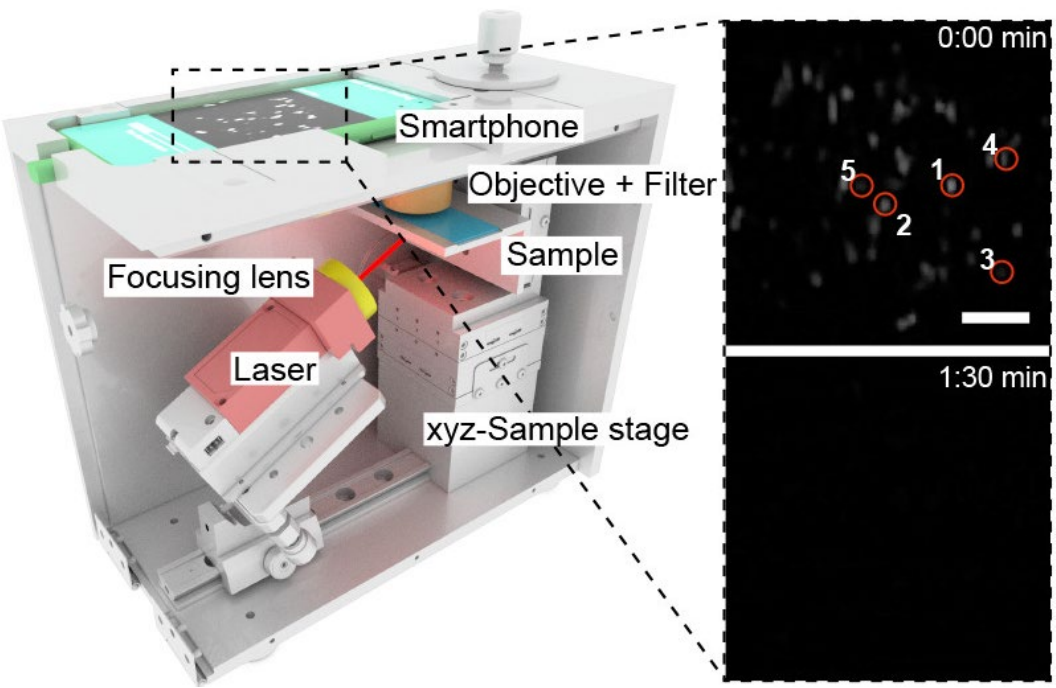
Due to specific pairing/interactions among DNA bases, nanoscale structures can be "programmed" using specialized computer software. Anyone can create DNA nanostructures that self-assemble in a wide variety of shapes, for applications in cell biology, photonics, quantum sensing and computing, and many other fields.

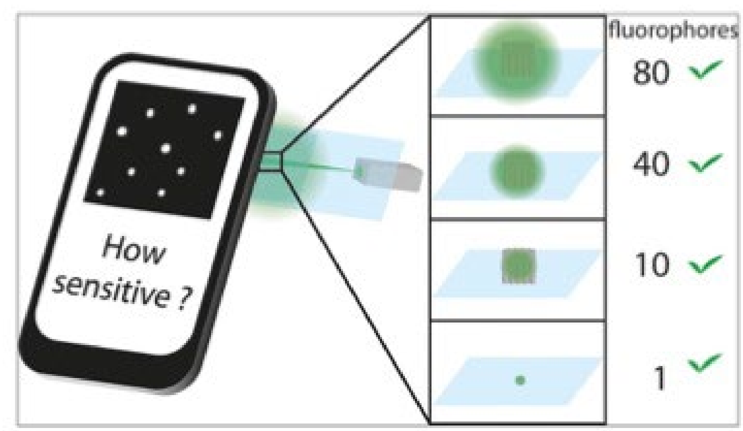
Building nano-sensors with DNA





Electric field increases between quantum dots, increasing emitted light signal, making detection and diagnosis possible with smart phones.





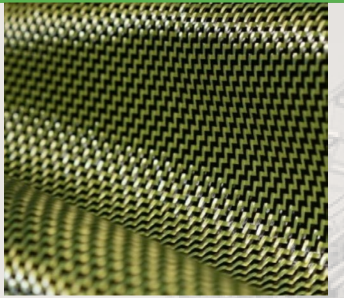
Nat. Commun. **2021**, *12*, 950

DOI: 10.1038/s41467-021-21238-9

Blueprint question

LDPE

HDPE



Kevlar

Nylon

What factors need to be considered when designing polymers for various applications?

http://toyworth.com/browse/action/figure/Star/Wars/89/1979/Accessories/Millennium/Falcon.html
https://www.boiseweekly.com/CityDesk/archives/2015/03/24/video-north-idaho-pranksters-stretching-saran-wrap-across-highway
https://www.acparadise.com/acp/display.php?c=71400 https://sites.google.com/site/carloswilson291126/kevlar
http://www.jotun.com/ww/en/b2b/paintsandcoatings/chemical-plants/

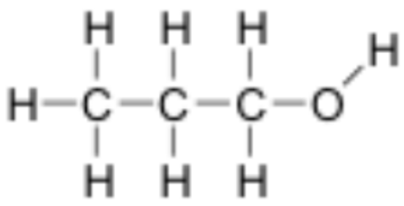
Polymers – Learning objectives

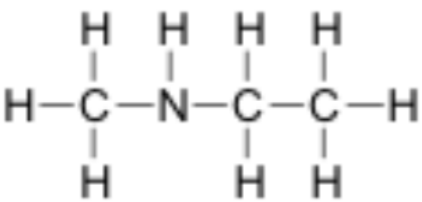
- Draw and interpret line bond structures and condensed Lewis structures.
- Describe the growth of polymers through addition and condensation reactions and predict which of these processes is likely to be important for a given monomer.
- Predict the structure of the monomer involved in the formation of a given polymer.
- Identify the type and degree of polymerization and/or the by-products formed for a given polymer and/or monomer.
- Define the terms monomer, polymer, oligomer, molecular weight distribution, degree of polymerization, crosslinking and elastomers.
- Describe how polymer architecture, molecular weight, monomer type, and crosslinking affect polymer properties.

Condensed Lewis structure

- Bonds are implied by <u>grouping</u> (lines not shown).
- <u>Hydrogens are grouped</u> with the atoms they are bonded to.
- <u>Double or triple bonds</u> are <u>sometimes indicated</u> but <u>often omitted</u> in basic condensed forms.
- <u>Lone pairs</u> are usually <u>not shown</u>.

Lewis structures





Condensed structures

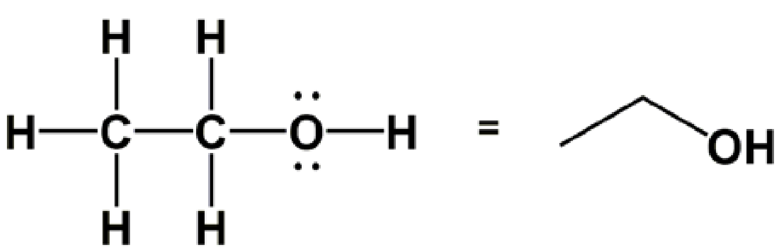
$CH_3CH_2CH_2OH$

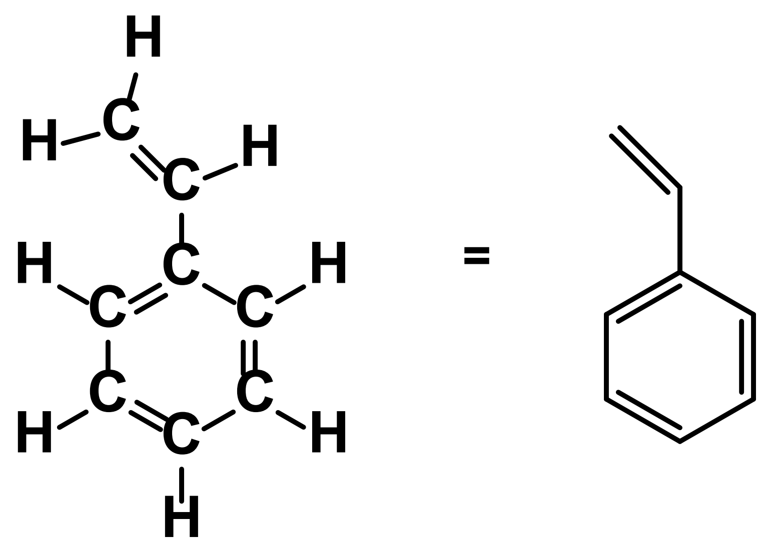
$CH_3NHCH_2CH_3$

Shorthand notation for organic molecules

Shorthand **“line” notation** for drawing organic molecules.

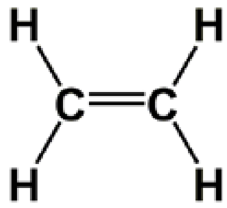
- Covalent bonds are drawn as lines.
- The end of each line indicates a carbon atom, unless otherwise specified.
- Each carbon atom has enough bonded H atoms to give it a formal charge of zero (i.e. a complete octet).
- Hydrogen atoms are only shown if they are bonded to an atom other than carbon.
- Lone pairs can be omitted.

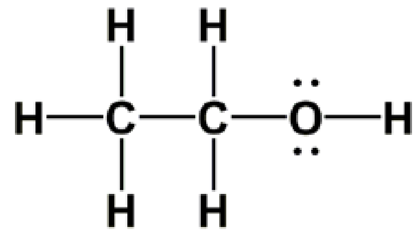


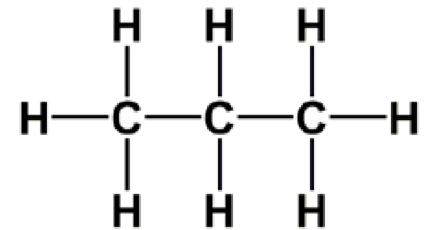


Condensed structures

Lewis structure

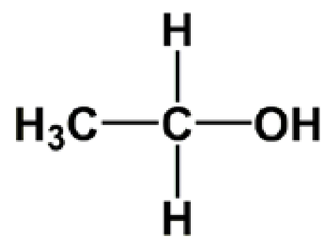


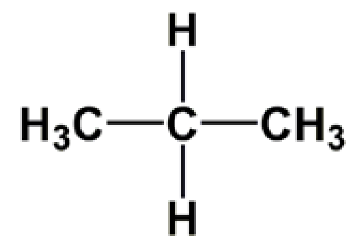




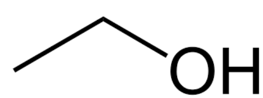
Condensed Lewis structure

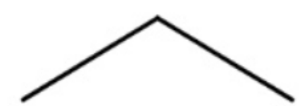
$H_2C{=}CH_2$





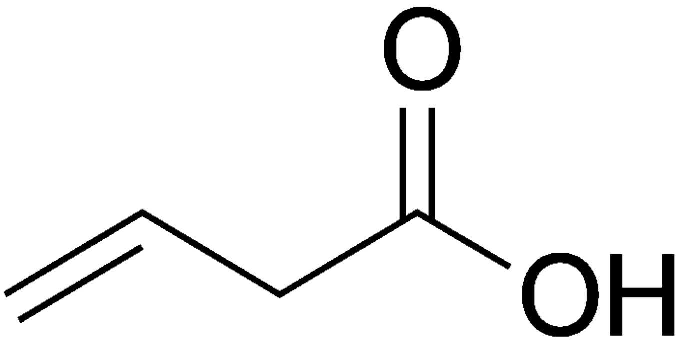
Line-bond structure





Clicker Question

Identify the total number of hydrogen atoms in this molecule:



A) 4

B) 5

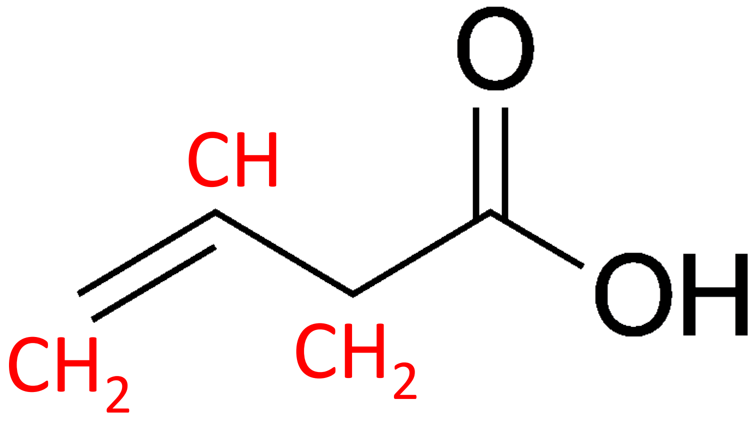
C) 6

D) 7

E) 8

Clicker Question

Identify the total number of hydrogen atoms in this molecule:



A) 4

B) 5

C) 6

D) 7

E) 8

Clicker Question

Identify the number of pairs of lone pairs in this molecule:

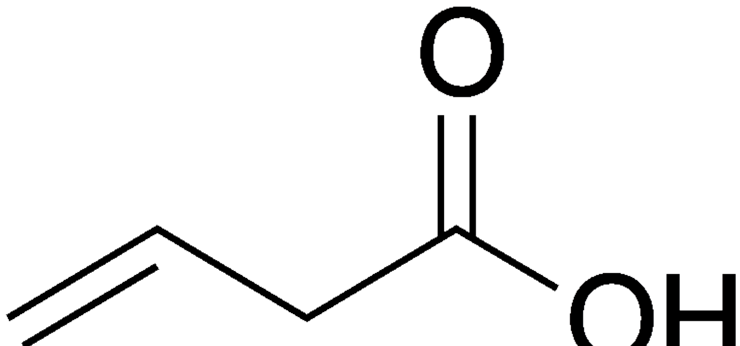
A) 0

B) 2

C) 4

D) 5

E) 6



Clicker Question

Identify the number of pairs of lone pairs in this molecule:

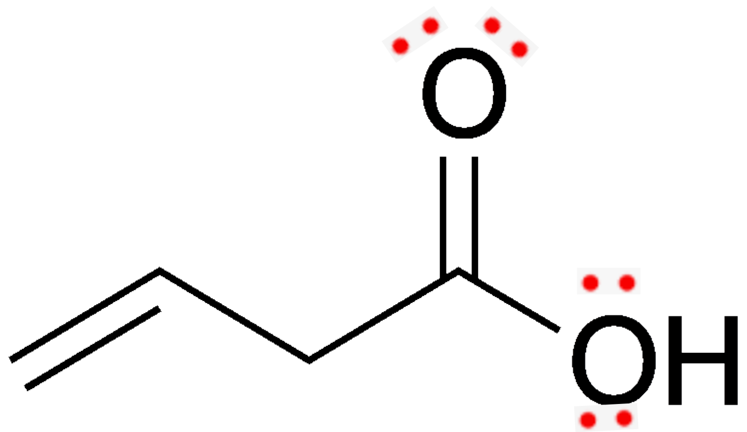
A) 0

B) 2

C) 4

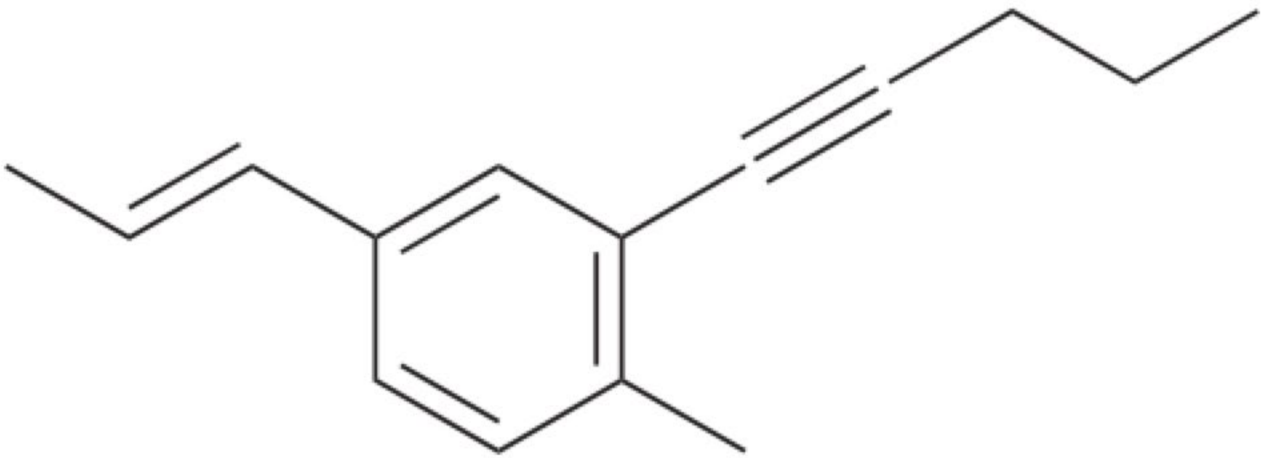
D) 5

E) 6



Clicker Question

Identify the number of carbon atoms in this molecule:



A) 12

B) 13

C) 14

D) 15

E) 16

Clicker Question

Identify the number of carbon atoms in this molecule:

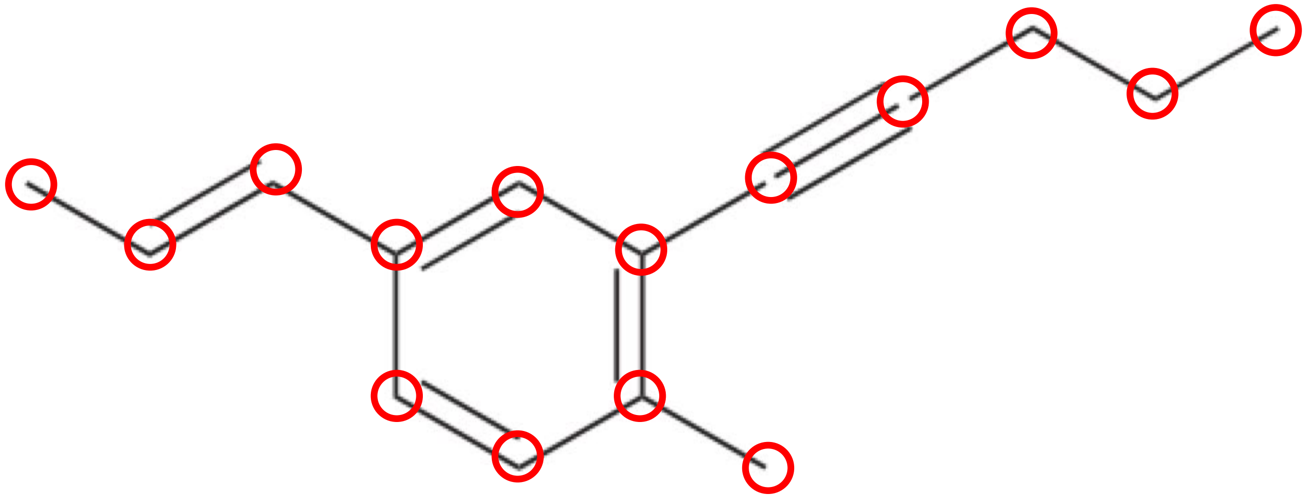
A) 12

B) 13

C) 14

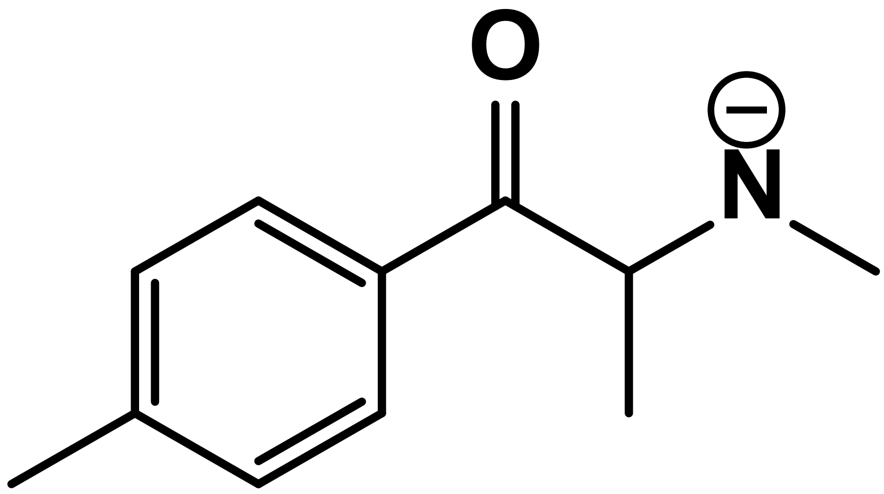
D) 15

E) 16

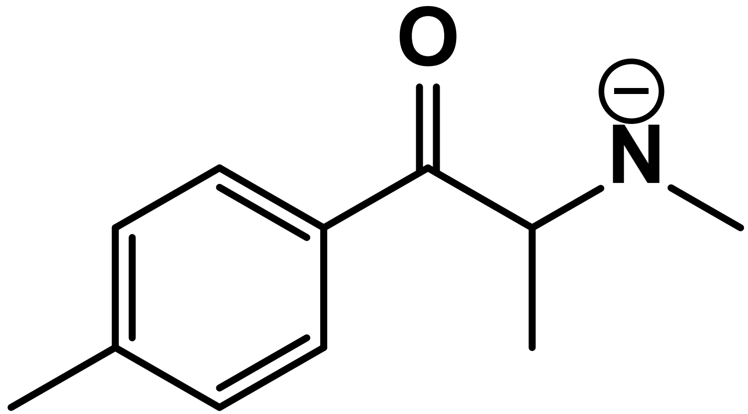


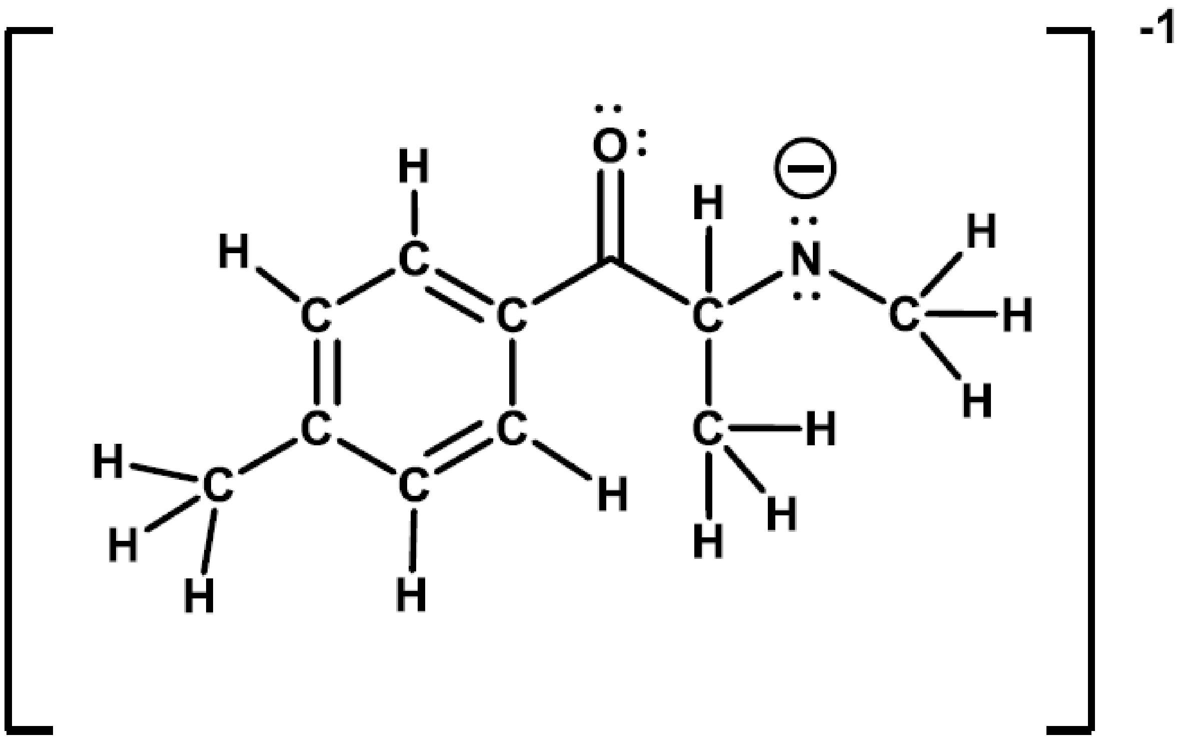
Worksheet Question #1

Mephedrone is a stimulant that can produce similar effects as cocaine. Starting from the shorthand notation of the deprotonated form of mephedrone below, draw its complete Lewis structure.



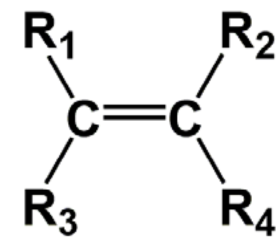
Worksheet Question #1

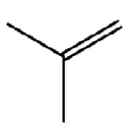




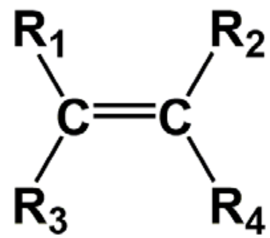
Worksheet Question #2

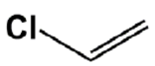
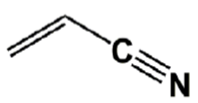
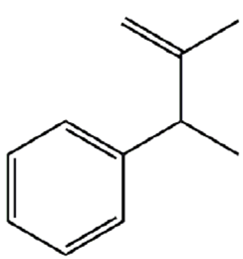
The molecules shown below can be used as monomers in a polymerization reaction. They can be drawn in the general form shown to the right. Complete the table below with the identity of R1, R2, R3, and R4. The first two rows are filled as an example.



Monomer	R_1	R_2	R_3	R_4
	H	H	H	H
	CH_3	H	CH_3	H

Worksheet Question #2

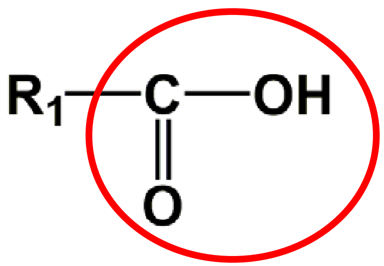


Monomer	R_1	R_2	R_3	R_4
	Cl	H	H	H
	H	H	H	CN
	H	CH_3	H	$C(H)(CH_3)C_6H_5$

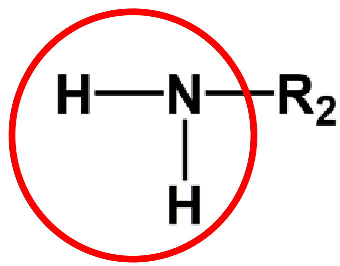
Functional groups

- Moieties in a molecule that have characteristic properties such as reactivity.
- An "R" substituent denotes a part of a molecule that is not relevant to the reactivity being discussed.

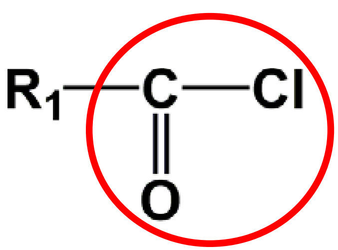
End Groups



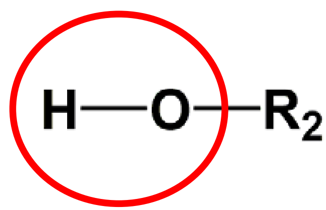
Carboxylic Acid



Amine

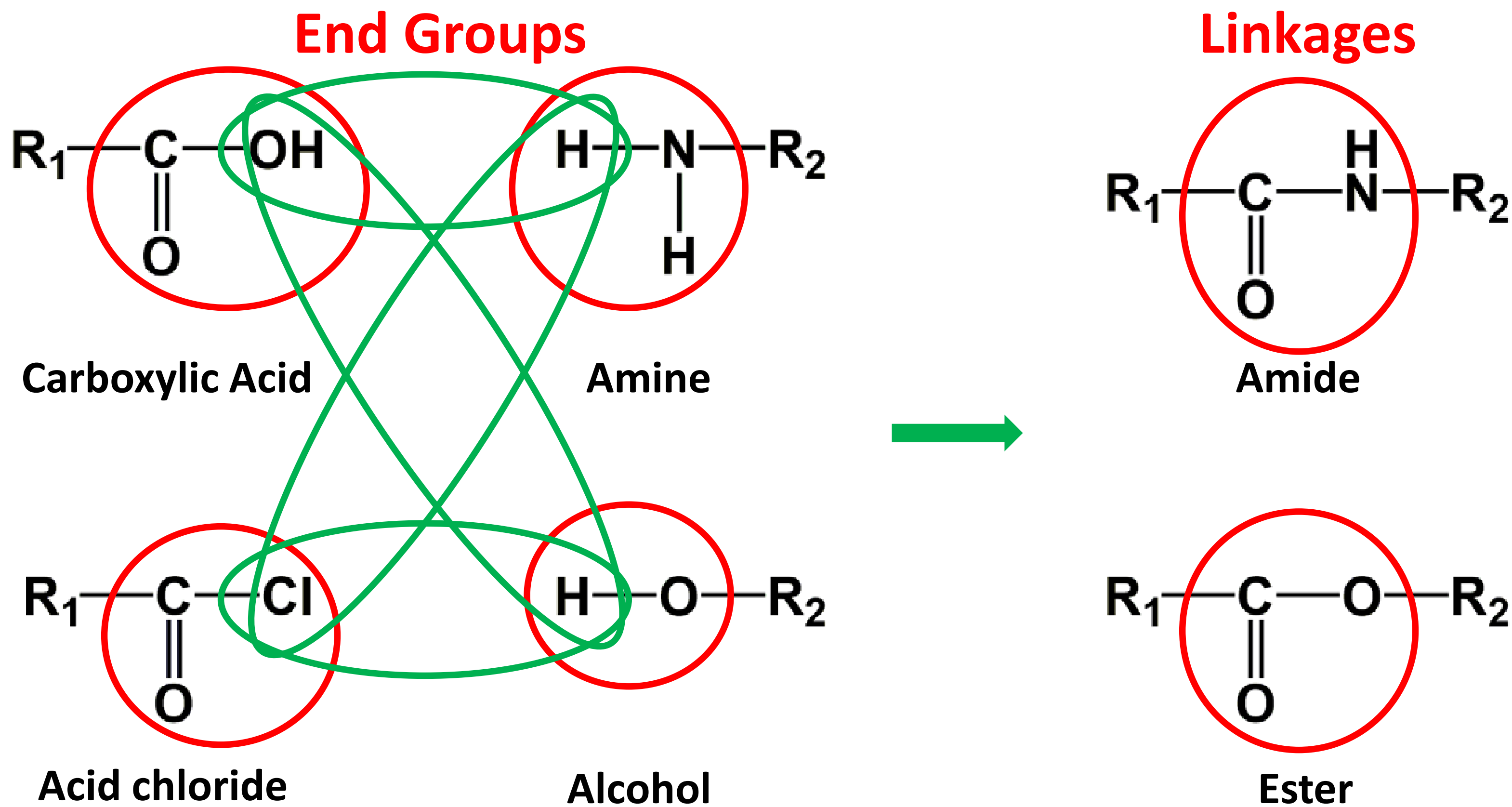


Acid chloride



Alcohol

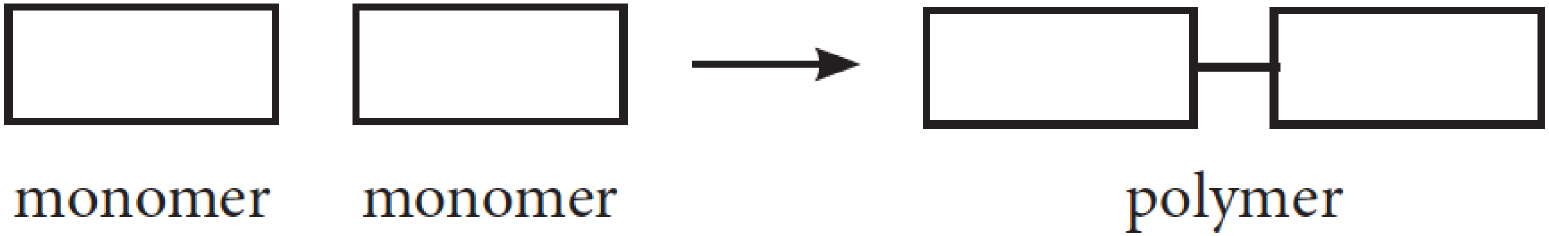
Linkages



End Groups
Linkages
R_1—C(=O)—OH
H—N(H)—R_2
Carboxylic Acid
Amine
R_1—C(=O)—Cl
H—O—R_2
Acid chloride
Alcohol
R_1—C(=O)—N(H)—R_2
Amide
R_1—C(=O)—O—R_2
Ester

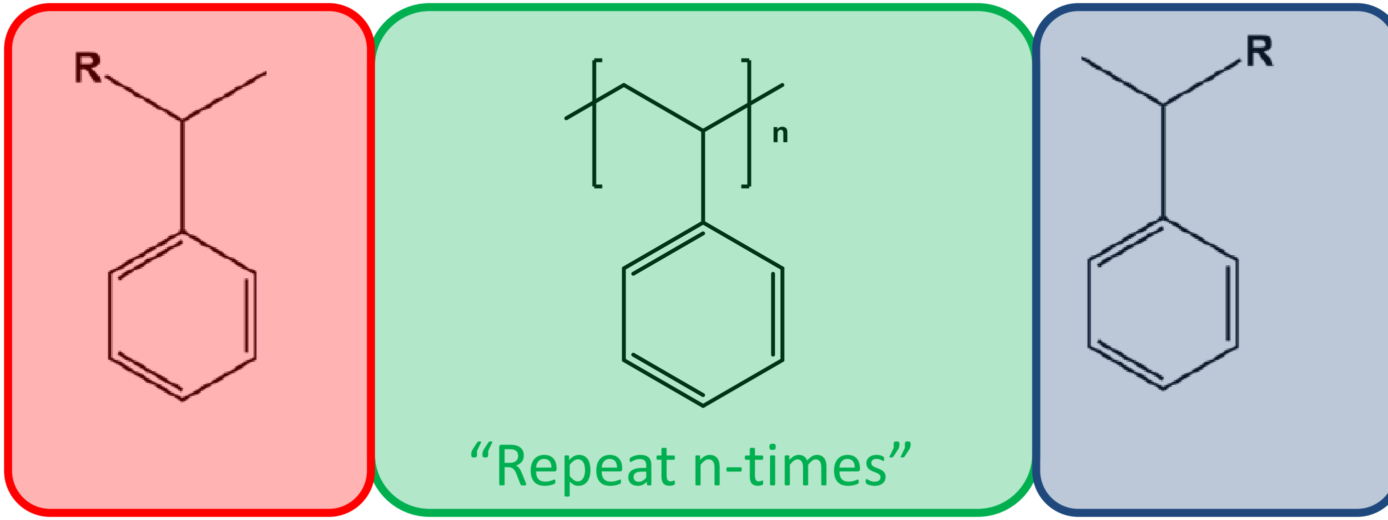
Polymers

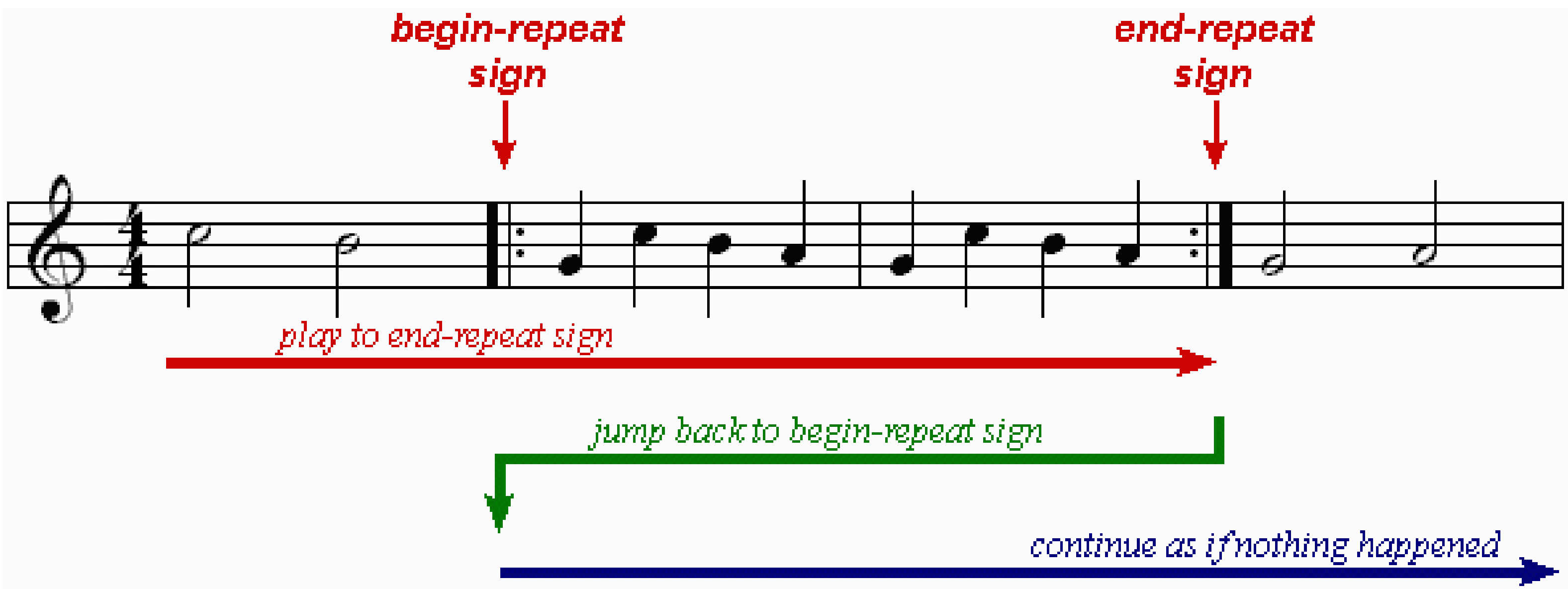
- A **polymer** is a macromolecule constructed by a sequential stringing together of smaller molecules called monomers.



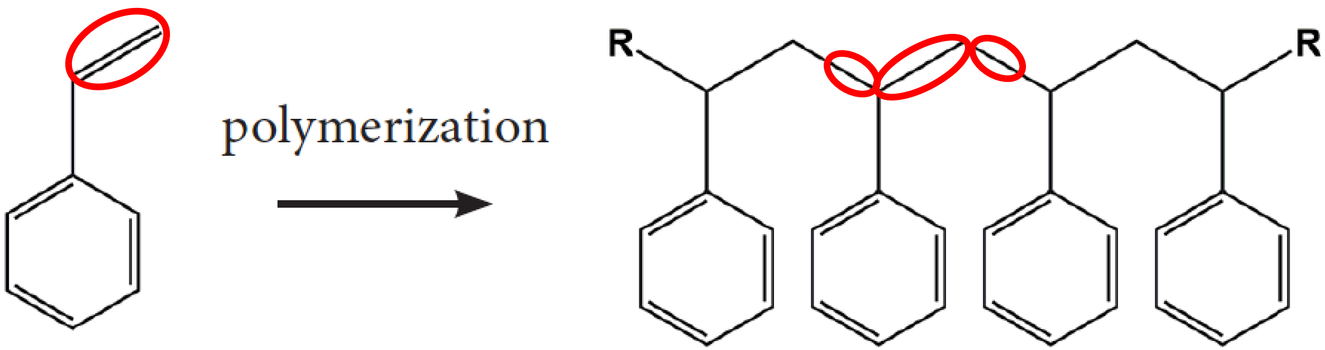
- We'll discuss two types of polymers:
  - **Condensation polymers**
  - **Addition polymers**

Repeating units: musical analogy





Shorthand notation for polymers

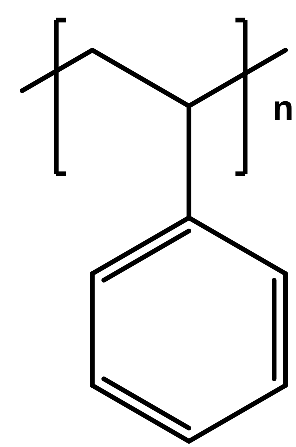


Styrene

Polystyrene

PS

- Another **shorthand notation** for polystyrene, where n is the number of monomers that make up polystyrene. The end groups (R) are generally not shown.



Degree of polymerization

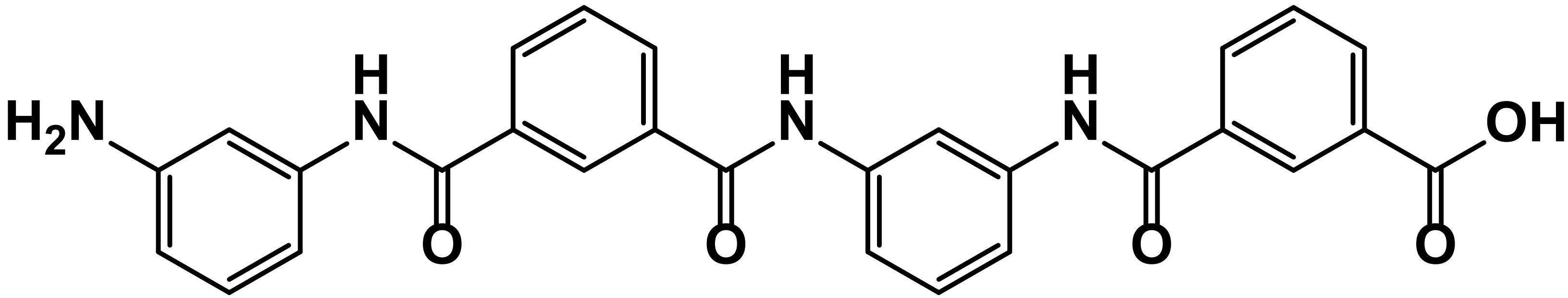
- The **degree of polymerization (DP)** is the number of repeat units in a polymer chain. For example:

Structure	DP
Dimer	2
Trimer	3
Tetramer	4
Pentamer	5
Oligomer	Small (typically 10s)
Polymer	Large (hundreds to millions)

Clicker Question

What is the degree of polymerization for the given molecule?

d)



a) 1

b) 2

c) 3

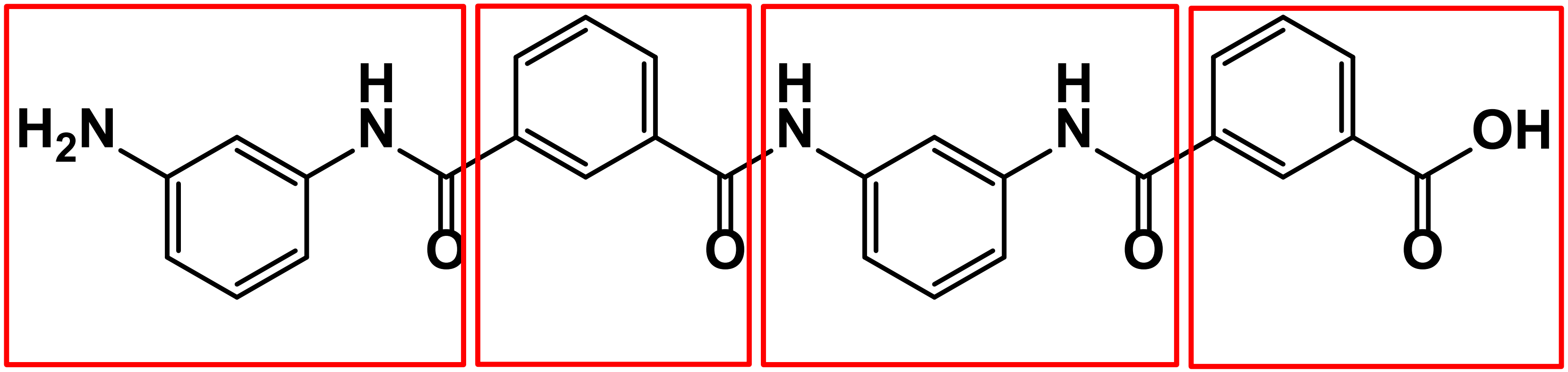
d) 4

e) 5

Clicker Question

What is the degree of polymerization for the given molecule?

d)



a) 1

b) 2

c) 3

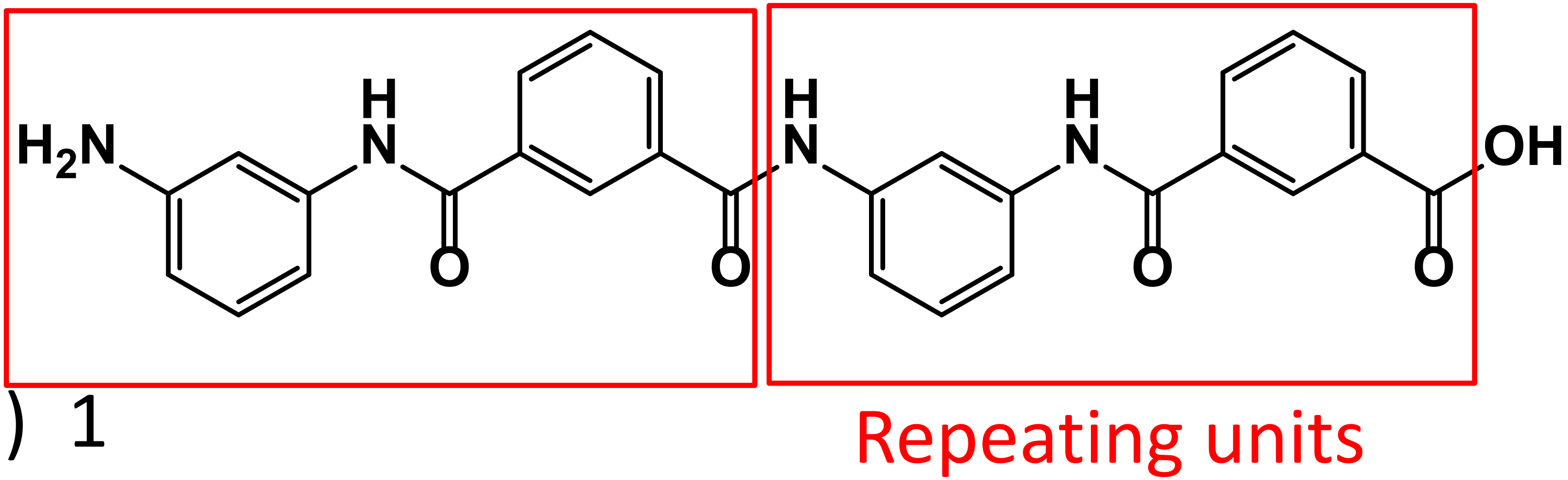
d) 4

e) 5

Not repeating units

Clicker Question

What is the degree of polymerization for the given molecule?

d) 

a) 1

b) 2

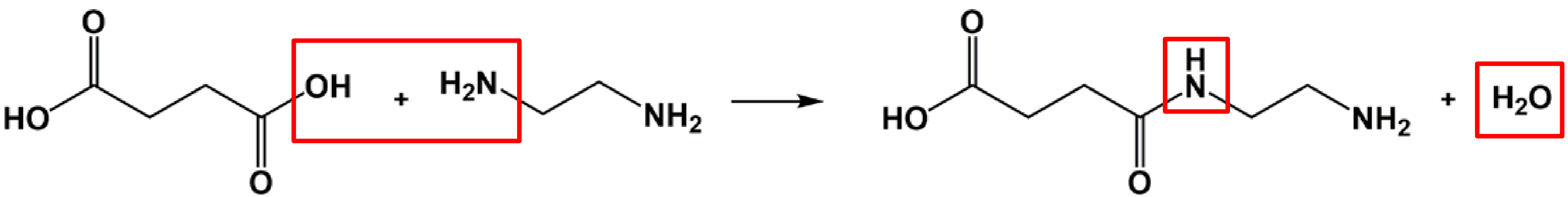
c) 3

d) 4

e) 5

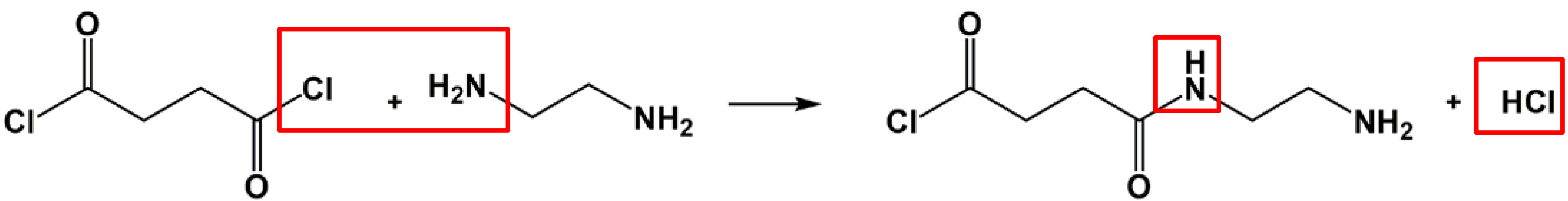
Condensation Polymers – Amide linkage

- Two monomers join together to form a polymer and a small molecule byproduct (<u>water</u> or <u>hydrochloric acid</u>).
- Condensation monomers have two reactive sites.
- An **amide linkage** is formed when <u>carboxylic acids</u> OR an <u>acid chloride</u> react with <u>amines</u>.
- The amide linkage repeats along backbone of polymer.



carboxylic acid + amine

amide

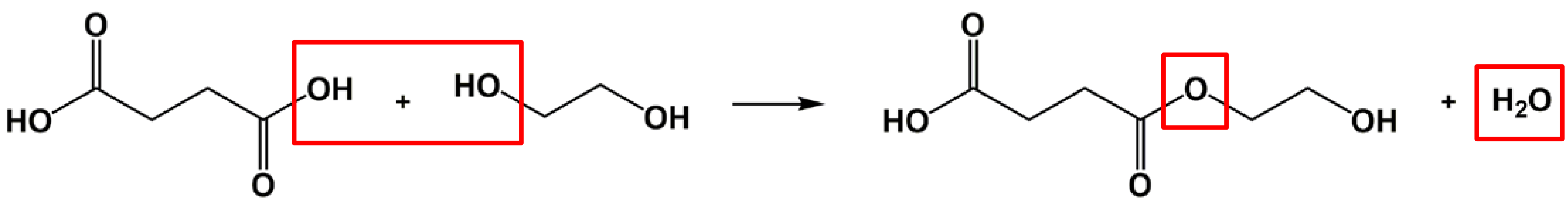


acid chloride + amine

amide

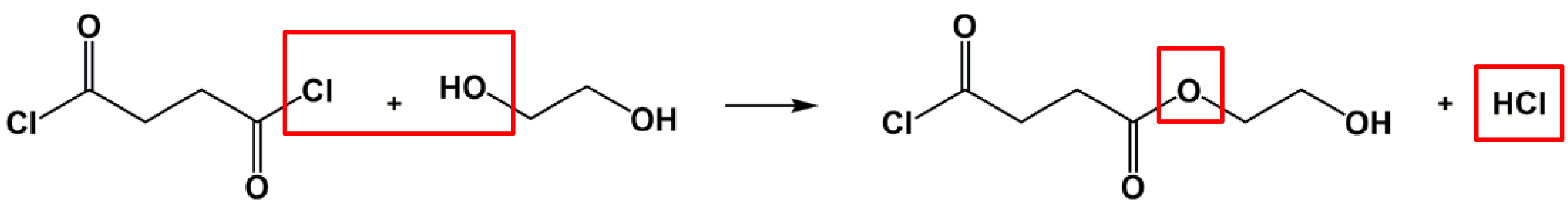
Condensation Polymers – Ester linkage

- An **ester linkage** is formed when carboxylic acid OR an acid chloride reacts with alcohols.
- The ester linkage repeats along the backbone of the polymer.



carboxylic acid + alcohol

Ester



acid chloride + alcohol

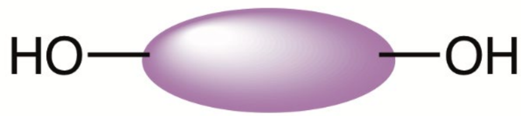
Ester

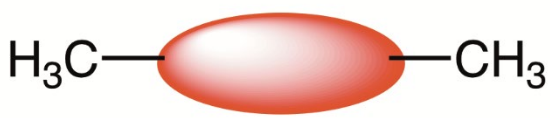
Summary of condensation polymer reactivity

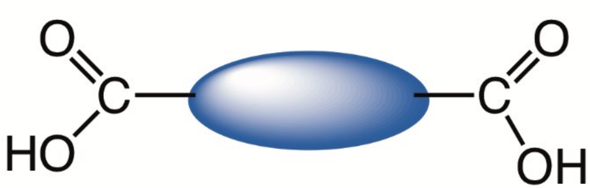
Reactant 1	Reactant 2	Polymer linkage	Small molecule
Carboxylic acid	Amine	Amide	Water
Acid chloride	Amine	Amide	HCl
Carboxylic acid	Alcohol	Ester	Water
Acid chloride	Alcohol	Ester	HCl

Clicker

Which cannot be a monomer for a condensation polymerization reaction?

A 

B 

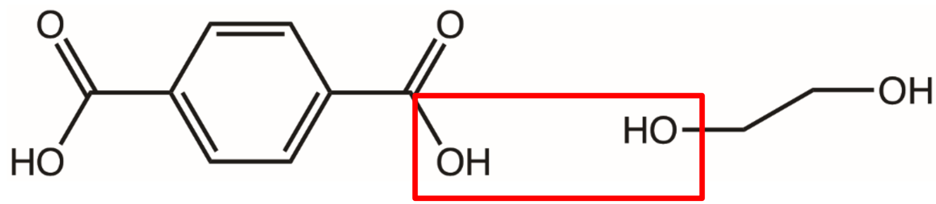
C 

D 

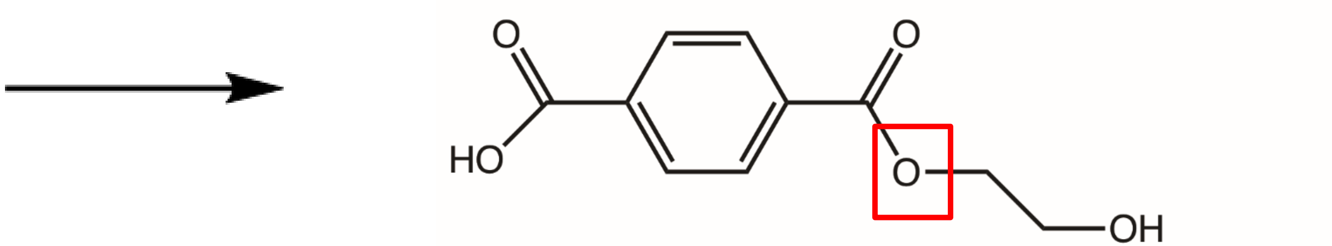
E 

Condensation polymer growth

Terephthalic Acid + Ethylene glycol

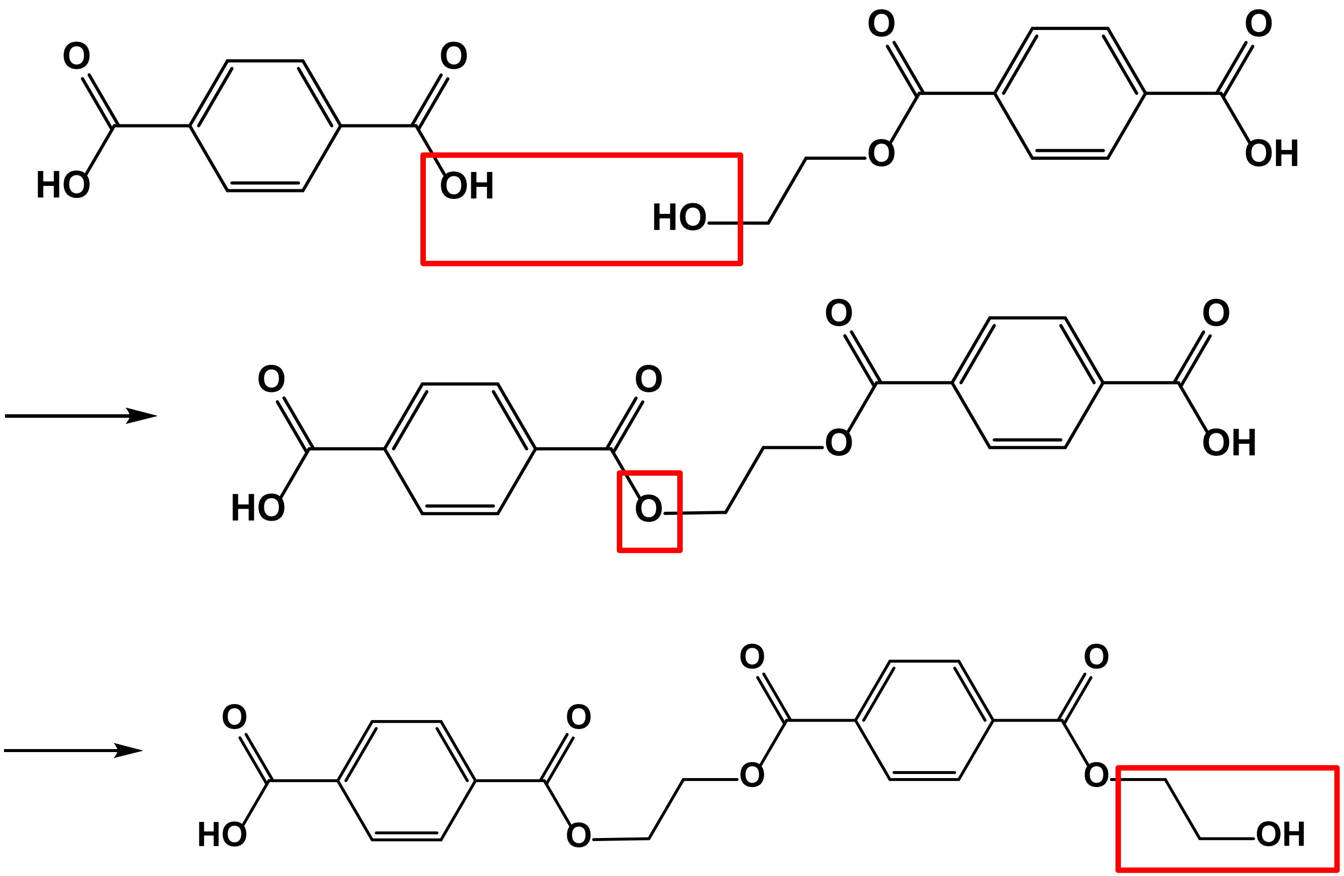


Carboxylic Acid **Alcohol**



Linkage: Ester bond (–CO–O–)

Condensation polymer growth

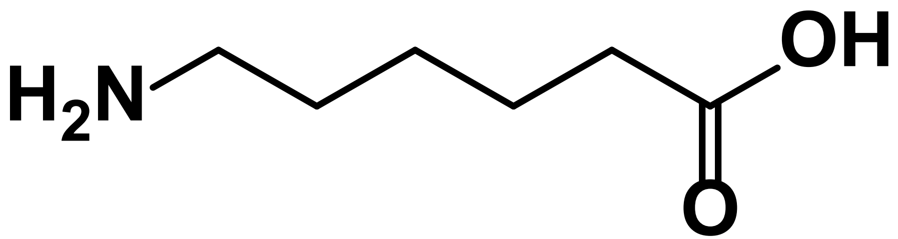


→ Polyethylene Terephthalate (PETE)

PETE

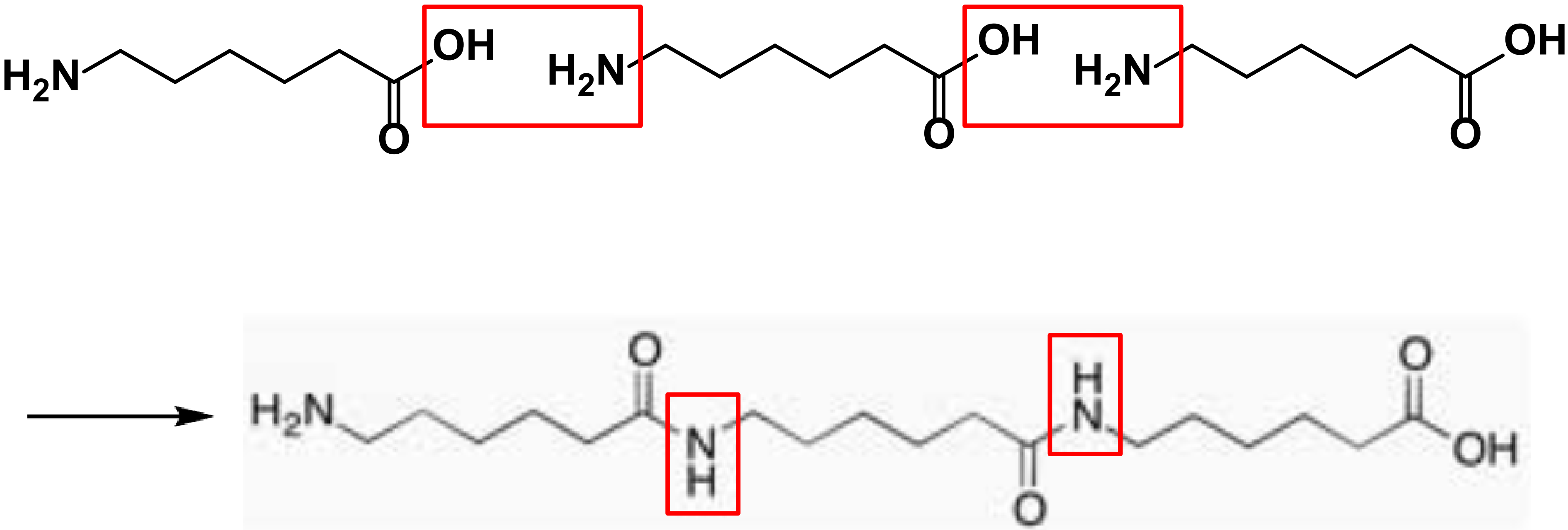
Worksheet Question #3

Draw the structure of the **trimer** and of a polymer resulting from the condensation of the monomer below.



Worksheet Question #3

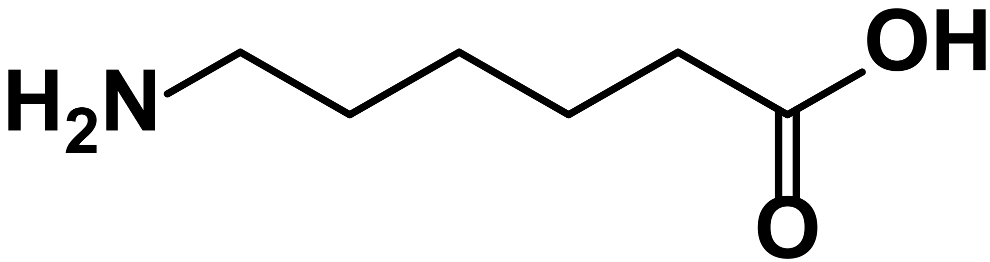
Draw the structure of the **trimer** and of a polymer resulting from the condensation of the monomer below.



Amide Linkages

Worksheet Question #3 (Clicker)

Draw the structure of the **trimer** and of a polymer resulting from the condensation of the monomer below. Name the linkage.

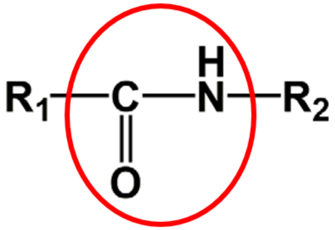


What kind of linkage will be formed?

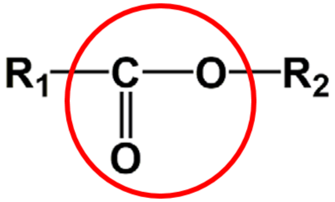
a) Ester

b) Amide

Linkage



Amide

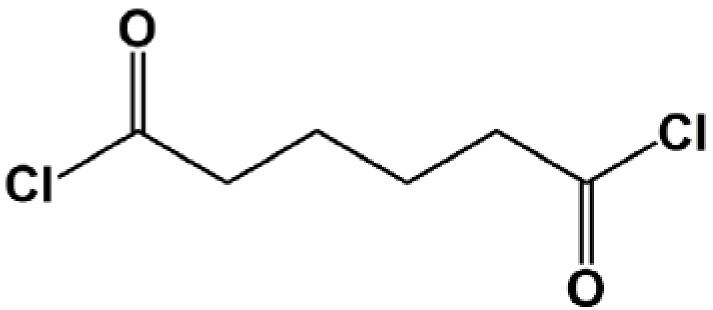


Ester

Worksheet Question #4 – GOOD QUESTION

Nylon is a polymer that can be prepared by the reaction of sebacoyl chloride and 1,6-diaminohexane.

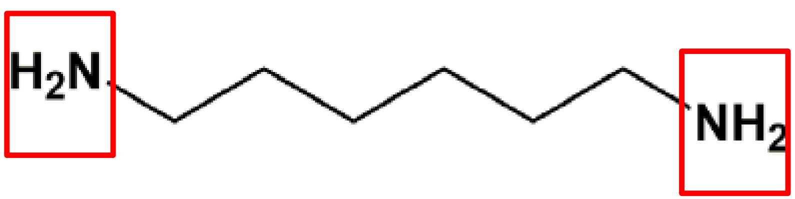
1,6-diaminohexane



Sebacoyl chloride

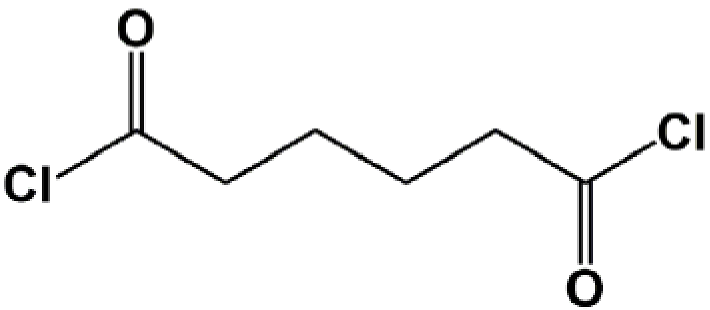
Worksheet Question #4 – GOOD QUESTION

– (a) A mixture of sebacoyl chloride in hexanes and 1,6-diaminohexane in water forms a biphasic mixture (a mixture with two layers). Provide possible reasons for this explanation.



1,6-diaminohexane

highly soluble in water (hydrogen bonds)

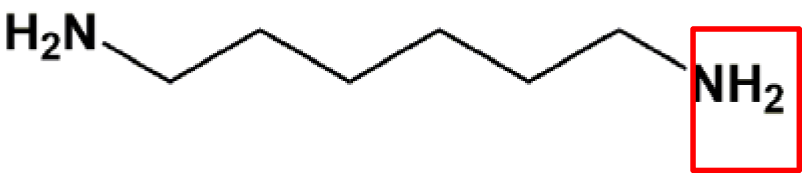


Sebacoyl chloride

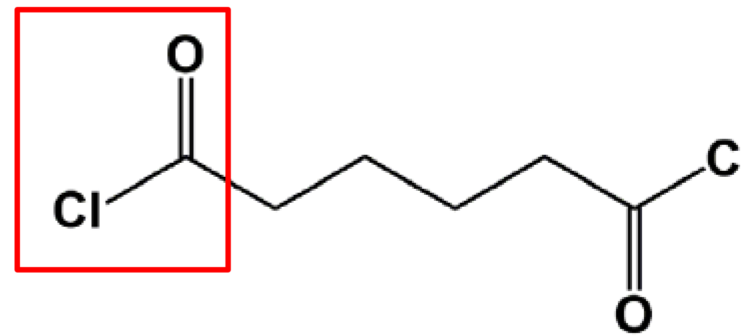
insoluble in water

Worksheet Question #4 – GOOD QUESTION

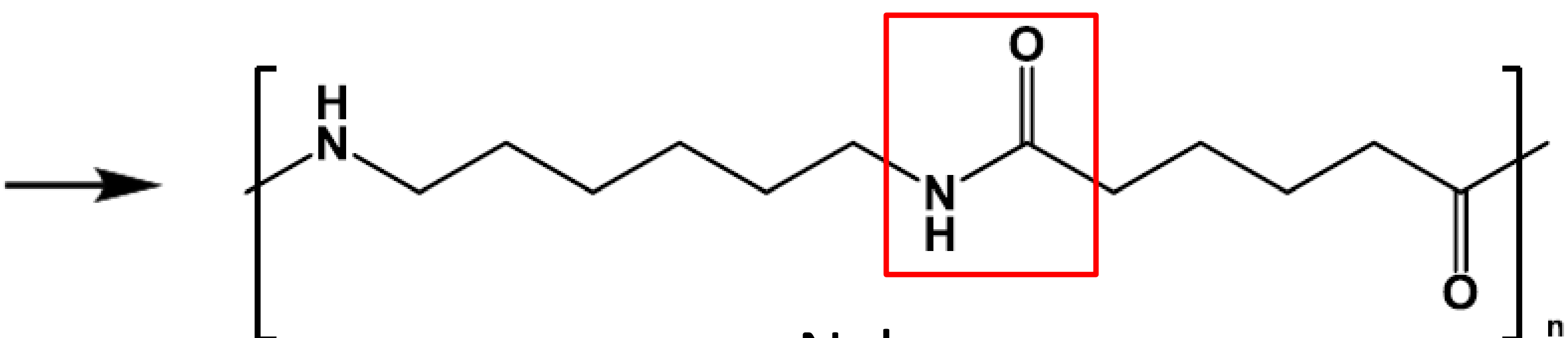
(b) Draw the product(s) of the reaction between sebacoyl chloride and 1,6-diaminohexane. Where does the reaction take place? Explain.



1,6-diaminohexane



Sebacoyl chloride

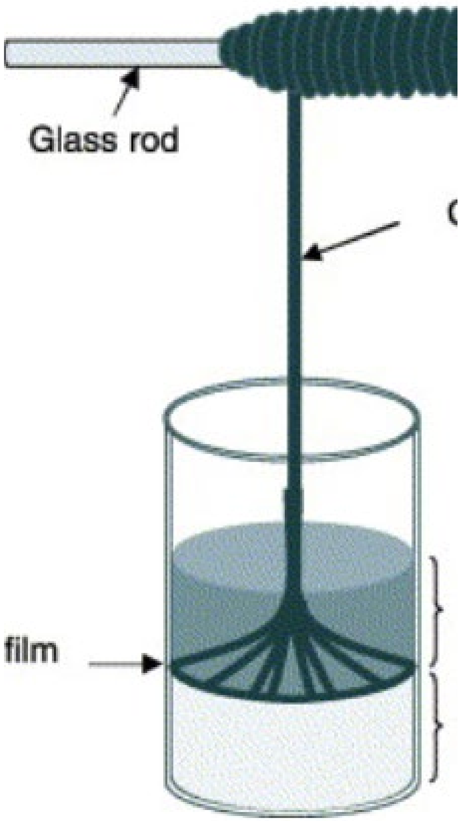


Nylon

Worksheet Question #4 – GOOD QUESTION

(b) Draw the product(s) of the reaction between sebacoyl chloride and 1,6-diaminohexane. Where does the reaction take place? Explain.

a) Bottom layer
b) Top layer
c) At the interface



Polymer, 47, 11, 17, 2006, 3961-3966