

# Polymers

How are polymers made from monomers, and what is the difference between addition and condensation polymers?

●●● Intermediate

Organic Chemistry

Last reviewed 5 October 2026

**Before you start:** it helps to understand [Reactions of Organic Compounds](#).

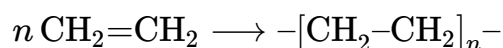
## What is it?

A **polymer** is a very large molecule made by joining many small molecules, called **monomers**, into a long chain. Plastics, rubber, nylon, DNA, proteins, starch and cellulose are all polymers.

- The **repeat unit** is the part of the chain that repeats over and over. It is drawn in brackets with an **n**, and the bonds at each end extend through the brackets.
- The **degree of polymerization**, **n**, is the number of repeat units in a chain, often thousands.

There are two ways to build a polymer:

- **Addition polymerization:** monomers with a **C=C** double bond join; the double bond opens and **nothing else** is formed.
- **Condensation polymerization:** monomers with **two functional groups** each join, and a **small molecule** (usually water) is released at every link.



### KEY IDEA

An addition polymer has the **same empirical formula** as its monomer, because all the atoms are kept. A condensation polymer contains **fewer atoms** than the monomers that made it, because water is lost at every link.

## Why does it matter?

- **Materials.** Poly(ethene) bags, PVC pipes, PTFE non-stick coatings, polyester and nylon clothing, and car tyres are polymers designed for particular properties.
- **Life.** Proteins (from amino acids), DNA (from nucleotides) and starch and cellulose (from glucose) are natural condensation polymers.

- **Environment.** Most plastics are not biodegradable, so their disposal, recycling and replacement are major environmental issues.

## How does it work?

### 1. Common addition polymers

| Monomer                                      | Polymer                 | Repeat unit                              | Uses                 |
|----------------------------------------------|-------------------------|------------------------------------------|----------------------|
| ethene, $\text{CH}_2=\text{CH}_2$            | poly(ethene)            | $-\text{[CH}_2-\text{CH}_2]-$            | bags, bottles        |
| propene, $\text{CH}_2=\text{CHCH}_3$         | poly(propene)           | $-\text{[CH}_2-\text{CH(CH}_3\text{)}]-$ | ropes, crates        |
| chloroethene, $\text{CH}_2=\text{CHCl}$      | poly(chloroethene), PVC | $-\text{[CH}_2-\text{CHCl]}-$            | pipes, window frames |
| tetrafluoroethene, $\text{CF}_2=\text{CF}_2$ | PTFE                    | $-\text{[CF}_2-\text{CF}_2]-$            | non-stick coatings   |

### 2. From monomer to repeat unit (and back)

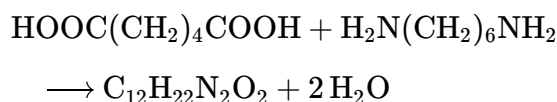
1. Draw the monomer with the  $\text{C}=\text{C}$  in the middle and the other groups above and below.
2. Change the  $\text{C}=\text{C}$  to a  $\text{C}-\text{C}$  single bond.
3. Add a bond sticking out from each carbon, through a pair of brackets, and write **n** after the closing bracket.

To find the monomer from a repeat unit, reverse this: take the two main-chain carbons, remove the end bonds and put back the  $\text{C}=\text{C}$ .

### 3. Condensation polymers

Each monomer needs **two** reactive groups, one at each end, so the chain can keep growing in both directions:

- **Polyesters** (such as PET, used for drinks bottles and fleece): a **dicarboxylic acid** + a **diol**, joined by **ester** links ( $-\text{COO}-$ ).
- **Polyamides** (such as nylon-6,6): a **dicarboxylic acid** + a **diamine**, joined by **amide** links ( $-\text{CONH}-$ ):



(Here  $\text{C}_{12}\text{H}_{22}\text{N}_2\text{O}_2$  is one repeat unit of the chain, with its two amide links.)

- **Proteins:** amino acids (each with an  $-\text{NH}_2$  and a  $-\text{COOH}$  group) joined by amide links, called **peptide** links.

### 4. Properties and disposal

- **Thermoplastics** (poly(ethene), PVC) are made of separate chains that slide past each other when heated, so they soften and can be remelted and recycled.

- **Thermosets** have **cross-links** (covalent bonds between chains), so they do not melt; they char when heated.
- Addition polymers have only strong, unreactive C–C and C–H bonds, so they are **not biodegradable** and persist for centuries. Condensation polymers can be broken down by **hydrolysis** at their ester or amide links, and some are designed to be biodegradable.
- Incineration recovers energy but releases CO<sub>2</sub>; burning PVC also releases toxic HCl gas.

### ∞ THINK OF IT LIKE THIS

Addition polymerization is like a line of people holding hands: each person (monomer) offers both hands (the C=C opens into two bonds), and nobody is left out. Condensation polymerization is like making a chain of paper clips where each join needs a small clip removed and thrown away: the water molecule lost at every link.

### 🔍 MORE PRECISELY

Real polymer samples contain chains of many different lengths, so their molar mass is an **average**, and *n* is an average degree of polymerization. The properties depend on chain length, branching and the forces between chains: low-density poly(ethene) has branched chains that pack loosely, while high-density poly(ethene) has straight chains that pack closely and are stronger. Nylon is strong because its amide groups form **hydrogen bonds** between neighbouring chains.

## Visualise it

### Two ways to build a polymer

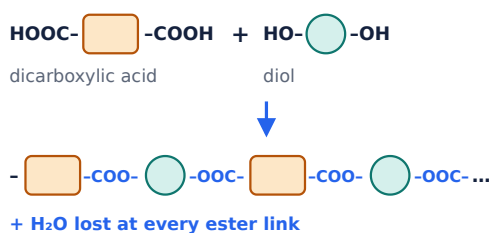
Addition joins C=C monomers; condensation releases water.

#### ADDITION



ethene (monomer) → poly(ethene): the C=C opens up; nothing else is formed. Repeat unit in brackets.

#### CONDENSATION (polyester)



Polyamides (nylon) form the same way, with –CONH– links.

Addition keeps every atom; condensation loses a water molecule at every link.

## Worked example

### WORKED EXAMPLE: Repeat units and monomers

**Question:** (a) Draw the repeat unit of the polymer made from chloroethene,  $\text{CH}_2=\text{CHCl}$ . (b) Name the monomer of the polymer with repeat unit  $-\text{[CF}_2-\text{CF}_2]-$ .

**Step 1** (a) Open the  $\text{C}=\text{C}$  and add a bond at each end:  $-\text{[CH}_2-\text{CHCl]}_n-$ , poly(chloroethene) (PVC).

**Step 2** (b) Take the two carbons and restore the double bond:  $\text{CF}_2=\text{CF}_2$ , **tetrafluoroethene**.

### WORKED EXAMPLE: Degree of polymerization

**Question:** A sample of poly(ethene) has an average molar mass of  $1.40 \times 10^5 \text{ g/mol}$ . How many repeat units are in an average chain? (repeat unit  $\text{C}_2\text{H}_4 = 28.05 \text{ g/mol}$ )

**Step 1** 
$$n = \frac{\text{molar mass of polymer}}{\text{molar mass of repeat unit}}$$

**Step 2** 
$$n = \frac{1.40 \times 10^5 \text{ g/mol}}{28.05 \text{ g/mol}} = 4.99 \times 10^3 \text{ repeat units (the units cancel)}$$

### WORKED EXAMPLE: Chlorine in PVC

**Question:** (a) What is the percentage by mass of chlorine in PVC? (b) What mass of HCl could form if all the chlorine in 1.00 kg of PVC were released on burning? (repeat unit  $\text{C}_2\text{H}_3\text{Cl} = 62.49 \text{ g/mol}$ ;  $\text{HCl} = 36.46 \text{ g/mol}$ )

**Step 1** (a) Each repeat unit has one Cl: 
$$\frac{35.45 \text{ g/mol}}{62.49 \text{ g/mol}} \times 100 \% = 56.7 \%$$

**Step 2** (b) 
$$n(\text{repeat units}) = \frac{1.00 \times 10^3 \text{ g}}{62.49 \text{ g/mol}} = 16.00 \text{ mol}$$

**Step 3** One HCl per repeat unit:  $n(\text{HCl}) = 16.00 \text{ mol}$

**Step 4** 
$$m(\text{HCl}) = 16.00 \text{ mol} \times 36.46 \text{ g/mol} = 583 \text{ g, which is why PVC must not be burned in the open.}$$

## Common mistake

### COMMON MISTAKE: Keeping the double bond in the repeat unit

In an addition polymer the  $\text{C}=\text{C}$  has **opened**: the repeat unit has a  $\text{C}-\text{C}$  single bond, with bonds extending through the brackets.  $-\text{[CH}_2=\text{CH}_2]-$  is wrong;  $-\text{[CH}_2-\text{CH}_2]-$  is right.

 **COMMON MISTAKE:** Putting side groups into the main chain

In poly(propene) the  $\text{CH}_3$  group is a **branch** on the chain, not part of it: the main chain has only two carbons per repeat unit,  $-\text{CH}_2-\text{CH}(\text{CH}_3)-$ .

 **COMMON MISTAKE:** Forgetting the small molecule in condensation

Every new ester or amide link releases one water molecule. Leave it out and the equation does not balance, and the polymer is wrongly given the full mass of the monomers.

 **NOTATION NOTE**

- Polymer names put the monomer name in brackets after “poly”: poly(ethene), poly(propene). Common names: polyethylene, polypropylene, polyvinyl chloride (PVC), Teflon (PTFE), polystyrene.
- The  $n$  after the brackets is the degree of polymerization, usually a large number (an average).
- Nylon-6,6 is named from the six carbons in each of its two monomers.

## Remember this

 **REMEMBER THIS**

- Polymer = many monomers joined; repeat unit in brackets with  $n$ .
- Addition: alkene monomers,  $\text{C}=\text{C}$  opens, no by-product; same empirical formula as the monomer.
- Condensation: two functional groups per monomer; water lost at every link; polyesters ( $-\text{COO}-$ ), polyamides and proteins ( $-\text{CONH}-$ ).
- $n = \text{polymer molar mass} \div \text{repeat-unit molar mass}$ .
- Thermoplastics remelt; thermosets are cross-linked. Addition polymers are not biodegradable; burning PVC gives HCl.

## References

1. Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E.; Murphy, C. J.; Woodward, P. M.; Stoltzfus, M. W. Chemistry: The Central Science, 15th ed.; Pearson, 2022.

Practise this topic with flashcards and a quiz at [chemistryclarity.com/chemistry/polymers/](https://chemistryclarity.com/chemistry/polymers/)