L4 - Learning Outcomes

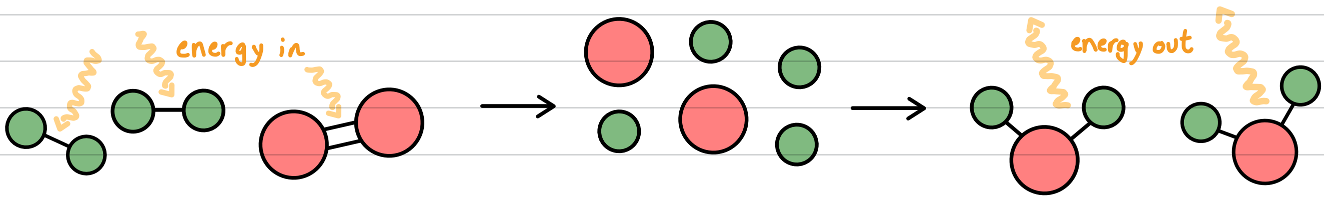
5.1 Exothermic and endothermic reactions
I can:

- ❑ 1. State that an exothermic reaction transfers thermal energy to the surroundings leading to an increase in the temperature of the surroundings
- ❑ 2. State that an endothermic reaction takes in thermal energy from the surroundings leading to a decrease in the temperature of the surroundings
- ❑ 3. Interpret reaction pathway diagrams showing exothermic and endothermic reactions
- ❑ 4. State that the transfer of thermal energy during a reaction is called the enthalpy change, ΔH, of the reaction. ΔH is negative for exothermic reactions and positive for endothermic reactions
- ❑ 5. Define activation energy, Ea, as the minimum energy that colliding particles must have to react
- ❑ 6. Draw and label reaction pathway diagrams for exothermic and endothermic reactions using information provided, to include:
  (a) reactants
  (b) products
  (c) enthalpy change of the reaction, ΔH
  (d) activation energy, Ea
- ❑ 7. State that bond breaking is an endothermic process and bond making is an exothermic process and explain the enthalpy change of a reaction in terms of bond breaking and bond making
- ❑ 8. Calculate the enthalpy change of a reaction using bond energies

Thermochemical equations

In chemical reactions, the bonds holding reactants together need to break, which <u>requires energy</u> while forming new bonds in the products <u>releases energy</u>

Activation Energy (E_a) : minimum energy required by colliding particles for a reaction



Enthalpy (H) : thermal energy (heat) in chemical reactions

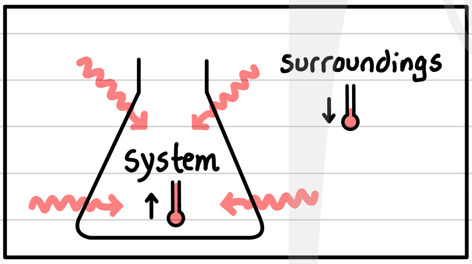
Enthalpy change (ΔH) : transfer of thermal energy in a chemical reaction

$$\Delta H_{reaction} = H_{reactants} - H_{products}$$

$\Delta H > 0$ (positive)

E used to break bonds > E released by forming bonds

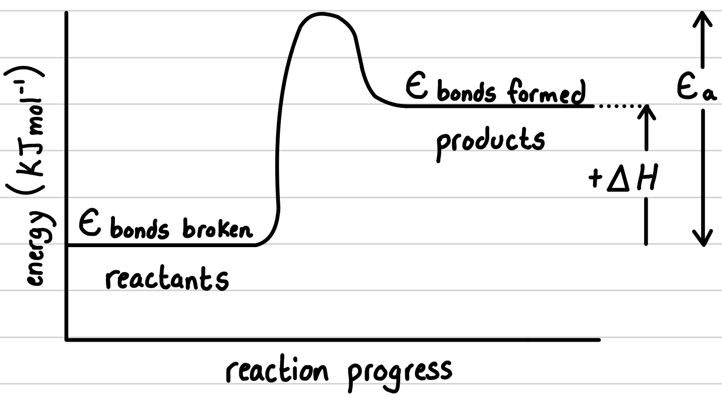
Endothermic reactions
- Endo → in, thermic → heat = taken in heat



- products have <u>more energy</u> than reactants
- takes in thermal energy from surroundings
- results in <u>decrease in temperature</u> of surroundings

ex: photosynthesis, cracking hydrocarbons

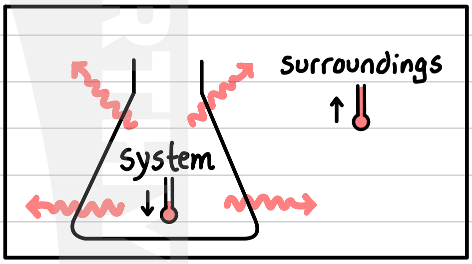
<u>reaction pathway diagram</u>:



$\Delta H < 0$ (negative)

E used to break bonds < E released by forming bonds

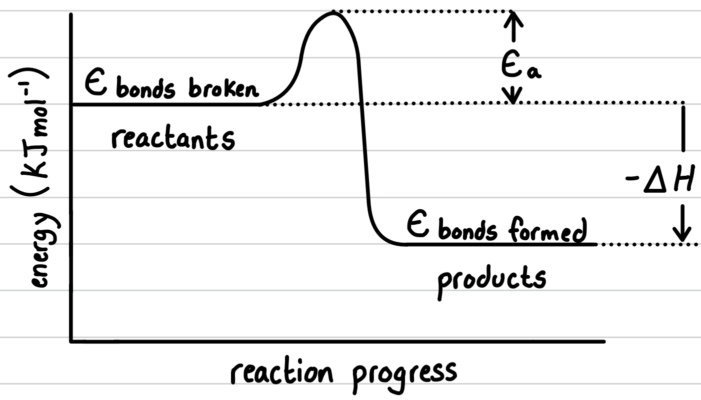
Exothermic reactions
- Exo → out, thermic → heat = releasing heat



- products have <u>less energy</u> than reactants
- transfers thermal energy to surroundings
- results in <u>increase in temperature</u> of surroundings

ex: combustion, cellular respiration, acid-base neutralization

<u>reaction pathway diagram</u>:



Bond energy : average bond-dissociation energy for a bond type in a particular molecule
i.e. a measure of bond strength
↳ amount of energy absorbed when bond is broken / energy released when bond is formed
↳ measured in $KJ\,mol^{-1}$

By calculating overall bond energy associated with reactants and products in a chemical reaction we can determine whether reaction is endothermic or exothermic

<u>Example problem</u> propanoic acid undergoes complete combustion.

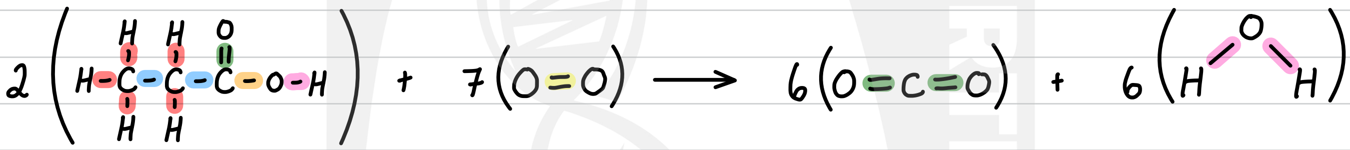
a) provide balanced chemical equation
b) calculate the enthalpy change for the reaction
c) determine whether reaction is endothermic or exothermic
d) draw the reaction pathway diagram for this reaction

Type of bond	Average energy (kJ/mol)
H—H	432
C—C	347
C=C	614
C≡C	839
C—H	413
C—O	358
C=O	745
O—H	467
O=O (in O_2)	498

<u>Step 1</u> write balanced chemical equation

$$2\,C_2H_5COOH + 7O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$$

<u>Step 2</u> draw the structural formulas



<u>Step 3</u> determine how many of each bond type for reactants and products and multiply by given bond energies

<u>reactants</u>
4 × C–C (347)
10 × C–H (413)
2 × C=O (745)
2 × C–O (358)
2 × O–H (467)
7 × O=O (498)

<u>products</u>
12 × C=O (745)
12 × O–H (467)

$E_{reactants} = 12144\ KJ\,mol^{-1}$

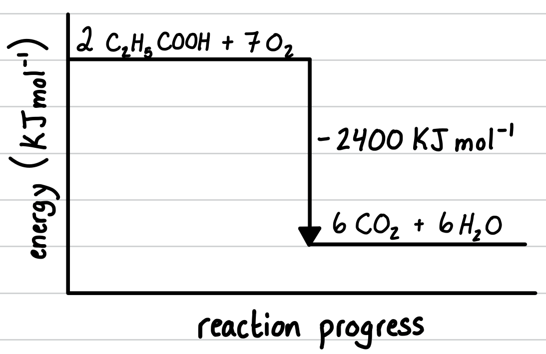
$E_{products} = 14544\ KJ\,mol^{-1}$

<u>Step 4</u> calculate ΔH and determine reaction type

$$\Delta H = H_{reactants} - H_{products}$$
$$= 12144\ KJ\,mol^{-1} - 14544\ KJ\,mol^{-1}$$
$$= -2400\ KJ\,mol^{-1}$$

$-\Delta H$ ∴ exothermic

<u>Step 5</u> Draw reaction pathway diagram



Practice problems

For each of the following molecules:

a) provide balanced chemical equation for its complete combustion
b) calculate the enthalpy change for its complete combustion
c) determine whether its complete combustion is endothermic or exothermic
d) draw the reaction pathway diagram for its complete combustion

Type of bond	Average energy (kJ/mol)
H—H	432
C—C	347
C═C	614
C≡C	839
C—H	413
C—O	358
C═O	745
O—H	467
O═O (in O_2)	498

① butane

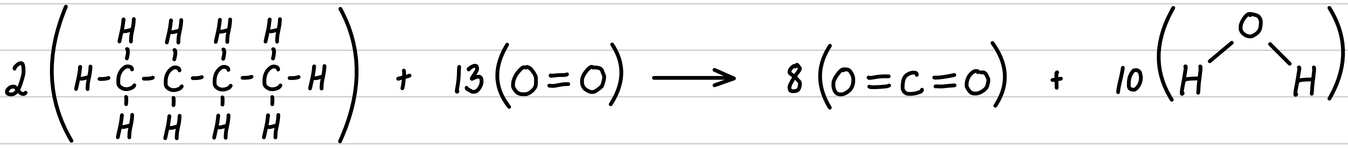
② oct-1-ene

③ pentan-3-ol

④ hexanoic acid

Answers

① $2\,C_4H_{10} + 13\,O_2 \longrightarrow 8\,CO_2 + 10\,H_2O$



reactants
- $6 \times C-C$ (347)
- $20 \times C-H$ (413)
- $13 \times O=O$ (498)

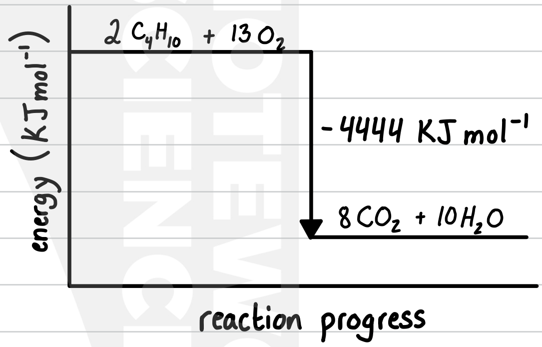
products
- $16 \times C=O$ (745)
- $20 \times O-H$ (467)

$E_{reactants} = 16816\ KJ\,mol^{-1}$

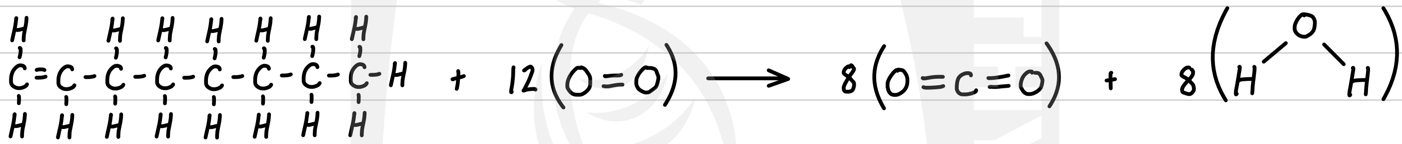
$E_{products} = 21260\ KJ\,mol^{-1}$

$\Delta H = H_{reactants} - H_{products}$
$= 16816\ KJ\,mol^{-1} - 21260\ KJ\,mol^{-1}$
$= -4444\ KJ\,mol^{-1}$

$-\Delta H$ ∴ exothermic



② $C_8H_{16} + 12\,O_2 \longrightarrow 8\,CO_2 + 8\,H_2O$



reactants
- $6 \times C-C$ (347)
- $16 \times C-H$ (413)
- $1 \times C=C$ (614)
- $12 \times O=O$ (498)

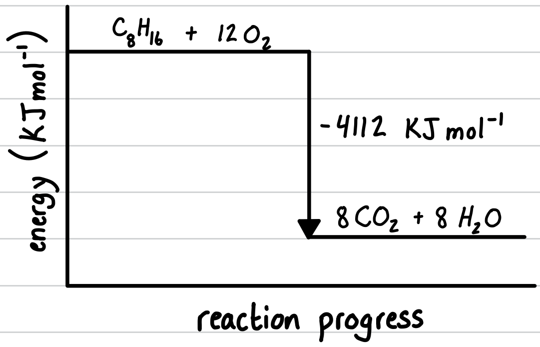
products
- $16 \times C=O$ (745)
- $16 \times O-H$ (467)

$E_{reactants} = 15280\ KJ\,mol^{-1}$

$E_{products} = 19392\ KJ\,mol^{-1}$

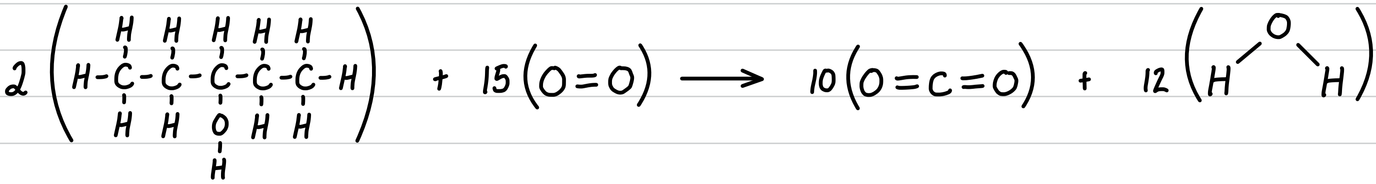
$\Delta H = H_{reactants} - H_{products}$
$= 15280\ KJ\,mol^{-1} - 19392\ KJ\,mol^{-1}$
$= -4112\ KJ\,mol^{-1}$

$-\Delta H$ ∴ exothermic



Answers

(3) $2\,C_5H_{11}OH + 15\,O_2 \longrightarrow 10\,CO_2 + 12\,H_2O$



reactants
- $8 \times C-C$ (347)
- $22 \times C-H$ (413)
- $2 \times O-H$ (467)
- $2 \times C-O$ (358)
- $15 \times O=O$ (498)

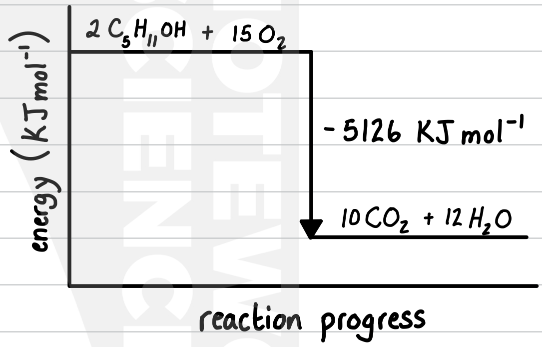
products
- $20 \times C=O$ (745)
- $24 \times O-H$ (467)

$E_{reactants} = 20982\ KJ\,mol^{-1}$

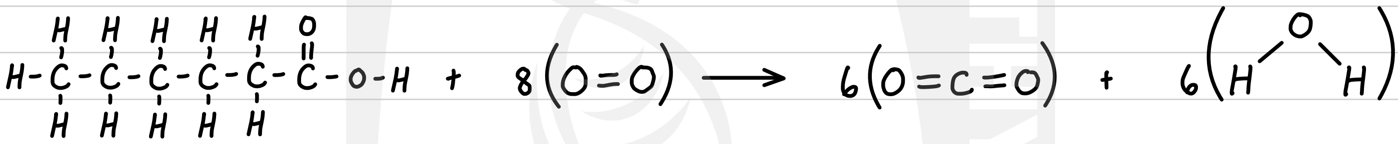
$E_{products} = 26108\ KJ\,mol^{-1}$

$\Delta H = H_{reactants} - H_{products}$
$= 20982\ KJ\,mol^{-1} - 26108\ KJ\,mol^{-1}$
$= -5126\ KJ\,mol^{-1}$

$-\Delta H$ ∴ exothermic



(4) $C_5H_{11}COOH + 8\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$



reactants
- $5 \times C-C$ (347)
- $11 \times C-H$ (413)
- $1 \times C=O$ (745)
- $1 \times C-O$ (358)
- $1 \times O-H$ (467)
- $8 \times O=O$ (498)

products
- $12 \times C=O$ (745)
- $12 \times O-H$ (467)

$E_{reactants} = 11832\ KJ\,mol^{-1}$

$E_{products} = 14544\ KJ\,mol^{-1}$

$\Delta H = H_{reactants} - H_{products}$
$= 11832\ KJ\,mol^{-1} - 14544\ KJ\,mol^{-1}$
$= -2712\ KJ\,mol^{-1}$

$-\Delta H$ ∴ exothermic