The energy change of reactions (HT only)

5.5.1.3 · Chemistry · revision notes

Higher tier only. Bond energies explain why a reaction is exothermic or endothermic: breaking bonds takes in energy and making bonds releases it. You need to calculate the overall energy change of a reaction from bond energies given in the question (usually 4 to 5 marks) and explain the result in terms of bonds.

Key facts

- Breaking bonds: energy taken in (endothermic)
- Overall energy change = bonds broken − bonds made
- Exothermic: energy released making bonds > energy needed to break bonds
- H_2O: two O–H bonds. CO_2: two C=O bonds. CH_4: four C–H bonds
- Bond energies are in kJ/mol
- Making bonds: energy released (exothermic)
- Negative answer = exothermic; positive answer = endothermic
- Endothermic: energy needed to break bonds > energy released making bonds
- O_2: one O=O bond. N_2: one N≡N bond

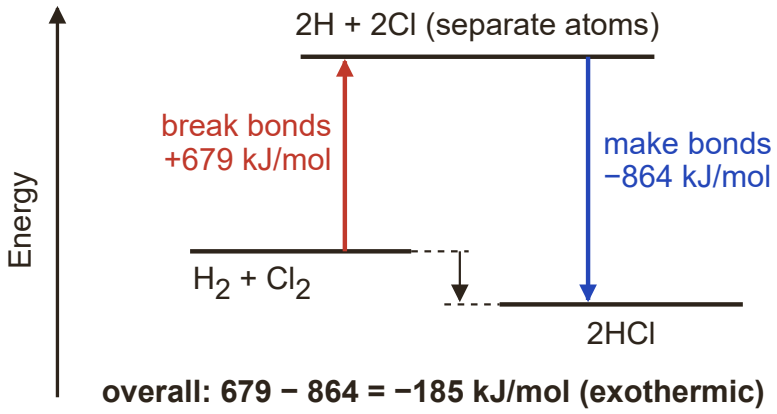
Notes

Breaking and making bonds

- During a reaction, bonds in the reactants break and new bonds form in the products.
- Breaking bonds **needs** energy: energy must be supplied (an endothermic process).
- Making bonds **releases** energy (an exothermic process).
- A **bond energy** is the energy needed to break one mole of a particular bond, in kJ/mol. The same amount of energy is released when one mole of that bond forms.

Exothermic or endothermic?

- **Exothermic**: the energy released forming new bonds is **greater** than the energy needed to break the existing bonds.
- **Endothermic**: the energy needed to break the existing bonds is **greater** than the energy released forming new bonds.



$H_2 + Cl_2 \rightarrow 2HCl$: more energy is released making bonds than is needed to break them, so the reaction is exothermic.

Calculating the overall energy change

- Overall energy change = total energy needed to break the bonds in the reactants − total energy released forming the bonds in the products.
- A **negative** answer means the reaction is exothermic. A **positive** answer means it is endothermic.
- Step 1: write out the displayed formula of every molecule, so you can see every bond.
- Step 2: count each type of bond, multiplying by the balancing numbers in the equation.
- Step 3: add up the energy for all the bonds broken, then for all the bonds made.
- Step 4: subtract: bonds broken − bonds made. Give the sign and the unit kJ/mol.
- Use the right bond: C=O (double) and C–O (single) have different energies. Oxygen, O=O, has a double bond and nitrogen, N≡N, has a triple bond.
- Example: $H_2 + Cl_2 \rightarrow 2HCl$, with H–H = 436, Cl–Cl = 243 and H–Cl = 432 kJ/mol. Bonds broken = 436 + 243 = 679 kJ/mol. Bonds made = 2 × 432 = 864 kJ/mol. Overall energy change = 679 − 864 = −185 kJ/mol, so the reaction is exothermic.

How to answer each type of question

Explain, in terms of bonds, why a reaction is exothermic or endothermic

1 to 2 marks | Grade 6

1. Decide which is bigger: the energy needed to break the bonds in the reactants, or the energy released when the bonds in the products form.
2. Exothermic: more energy is released making bonds than is needed to break bonds.
3. Endothermic: more energy is needed to break bonds than is released making bonds.
4. If numbers are given, quote them in your answer.

Example. For the reaction $2HI \rightarrow H_2 + I_2$:
energy needed to break the bonds in the reactants = 598 kJ/mol
energy released when the bonds in the products form = 587 kJ/mol
Explain, in terms of bonds, whether the reaction is exothermic or endothermic. (2)

Model answer. Endothermic (1). More energy is needed to break the H–I bonds (598 kJ/mol) than is released when the H–H and I–I bonds form (587 kJ/mol) (1).

Calculate the overall energy change (simple reaction)

3 marks | Grade 7

1. List every bond broken in the reactants and every bond made in the products, multiplied by the number of molecules.
2. Add up the energy for the bonds broken and for the bonds made separately.
3. Overall energy change = bonds broken − bonds made.
4. Give the sign and the unit, kJ/mol.

Example. Hydrogen reacts with fluorine to produce hydrogen fluoride.
H–H + F–F → 2 H–F

Bond	H–H	F–F	H–F
Bond energy in kJ/mol	436	158	568

Calculate the overall energy change for this reaction. (3)

Model answer.

Bonds broken: 436 + 158 = 594 kJ/mol (1)
Bonds made: 2 × 568 = 1136 kJ/mol (1)
Overall energy change = 594 − 1136 = −542 kJ/mol (1)

Calculate the overall energy change (many bonds, e.g. combustion)

3 to 4 marks | **Grade 8**

1. Write out each displayed formula and count the bonds in one molecule.
2. Multiply by the balancing number: $3O_2$ means three O=O bonds.
3. Tick off each bond as you count it so none are missed or counted twice.
4. Subtract bonds made from bonds broken, and check that the sign makes sense (combustion is exothermic).

Example. Ethene burns completely in oxygen.
$H_2C{=}CH_2 + 3\ O{=}O \rightarrow 2\ O{=}C{=}O + 2\ H{-}O{-}H$

Bond	C=C	C–H	O=O	C=O	O–H
Bond energy in kJ/mol	612	413	498	805	464

Calculate the overall energy change for this reaction. (4)

Model answer.

Bonds broken: 612 + (4 × 413) + (3 × 498) = 612 + 1652 + 1494 = 3758 kJ/mol (1)

Bonds made: (4 × 805) + (4 × 464) = 3220 + 1856 = 5076 kJ/mol (1)

Overall energy change = 3758 − 5076 (1)

= −1318 kJ/mol (1)

Calculate an unknown bond energy

4 to 5 marks | **Grade 9**

1. Start from: overall energy change = bonds broken − bonds made.
2. Put in all the values you know, and write the unknown bond energy as a letter (e.g. x) multiplied by the number of those bonds.
3. Rearrange carefully, keeping track of the negative sign.
4. Divide by the number of those bonds to find the energy of one bond.

Example. Nitrogen reacts with hydrogen to produce ammonia.
$N{\equiv}N + 3\ H{-}H \rightarrow 2\ NH_3$ (each NH_3 molecule has three N–H bonds)

The overall energy change for the reaction is −93 kJ/mol.

Bond	N≡N	H–H
Bond energy in kJ/mol	945	436

Calculate the bond energy of the N–H bond. (4)

Model answer.

Bonds broken: 945 + (3 × 436) = 945 + 1308 = 2253 kJ/mol (1)

Bonds made: 2 × 3 = 6 N–H bonds, so 6x (1)

2253 − 6x = −93, so 6x = 2253 + 93 = 2346 (1)

x = 2346 ÷ 6 = 391 kJ/mol (1)

Don’t lose marks

- Working out bonds made − bonds broken, which gives the right number with the wrong sign.
- Forgetting the balancing numbers, e.g. counting one O=O bond for $3O_2$ instead of three.
- Counting one O–H bond per water molecule instead of two, or one C=O bond per carbon dioxide molecule instead of two.
- Using the C–C or C–O value where the molecule has C=C or C=O.
- Leaving out the negative sign or the unit (kJ/mol) in the final answer.
- Writing 'breaking bonds releases energy'. It is the other way round: breaking bonds needs energy.

More tips

Memory tricks

- 'Break in, make out': breaking bonds takes energy in, making bonds gives energy out.
- Always 'broken minus made'. If the bonds made total is bigger, the answer must be negative (exothermic).
- Sense check: combustion and neutralisation are exothermic, so a positive answer for them means you have made a mistake.
- Check your displayed formulae: carbon makes 4 bonds, nitrogen 3, oxygen 2, and hydrogen and the halogens 1 each.
- Write the bond counts in a small table (bond, number, energy, total) for reactants and products. It makes it easy to spot a missed bond.

Exam technique

- Set out your working as two clear lines, 'bonds broken = ...' and 'bonds made = ...'. Each line can earn a mark even if your final answer is wrong.
- Always give the sign and the unit, e.g. −542 kJ/mol. The negative sign tells the examiner the reaction is exothermic.
- If the equation uses molecular formulae (e.g. CH_4), sketch the displayed formulae in the margin before you count.
- For 'explain in terms of bonds', compare the two amounts of energy using 'more' or 'less'. Just writing 'bonds are broken and made' does not score.
- If you are told the energy released forming new bonds is X kJ/mol greater than the energy needed to break bonds, the overall energy change is −X kJ/mol: write bonds broken − bonds made = −X.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 5 — **State energy changes in breaking and making bonds**
Breaking bonds needs energy to be supplied; making bonds releases energy.

Grade 6 — **Count the bonds in displayed formulae**
Find how many of each type of bond there are, e.g. H–O–H has two O–H bonds and O=C=O has two C=O bonds.

Grade 6 — **Explain exothermic or endothermic using bond energies**
Compare the energy needed to break the bonds with the energy released when the new bonds form.

Grade 7

Calculate the energy change for a simple reaction

Overall energy change = energy to break bonds − energy released making bonds, e.g. for $H_2 + Cl_2 \rightarrow 2HCl$.

Grade 8

Calculate energy changes involving many bonds

Multiply each bond energy by the number of bonds in a molecule and by the balancing number, e.g. for a combustion reaction.

Grade 9

Calculate an unknown bond energy

Put the known values into overall energy change = bonds broken − bonds made and rearrange to find the missing bond energy.

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