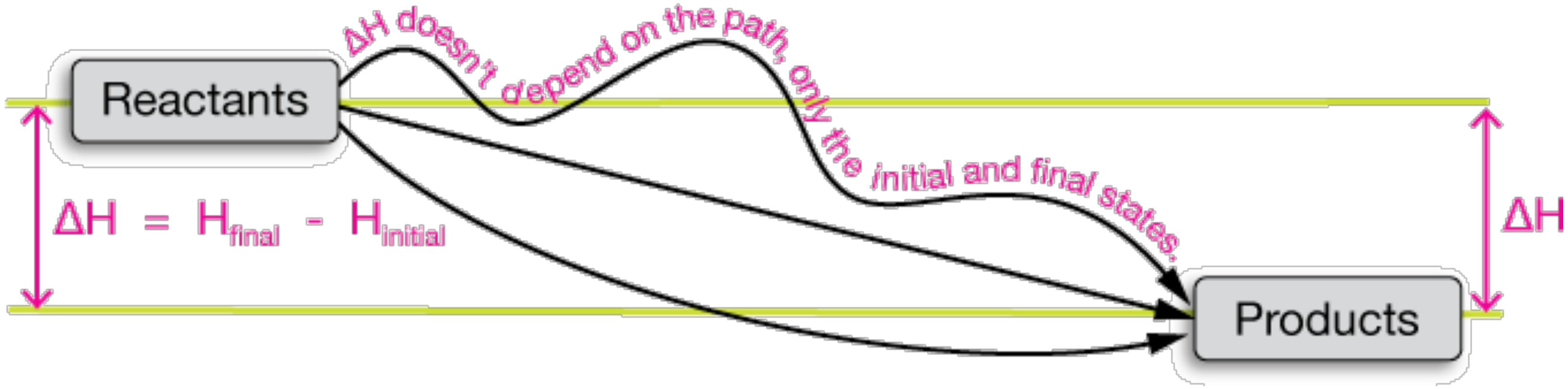
Bond Enthalpies & Strengths

DR. MIOY T. HUYNH
YALE UNIVERSITY
CHEMISTRY 161
FALL 2019

www.mioy.org/chem161

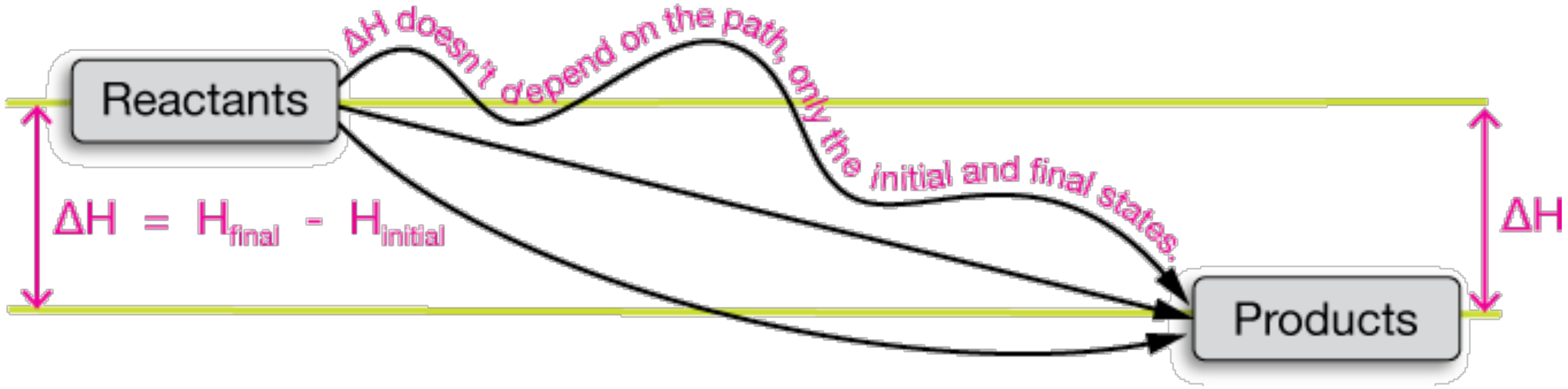
Review: Heats of Reactions (Δ*H*)

Remember that enthalpy is a state function, so we only care about the difference between the final state and the initial state.



Review: Heats of Reactions (Δ*H*)

Remember that enthalpy is a state function, so we only care about the difference between the final state and the initial state.



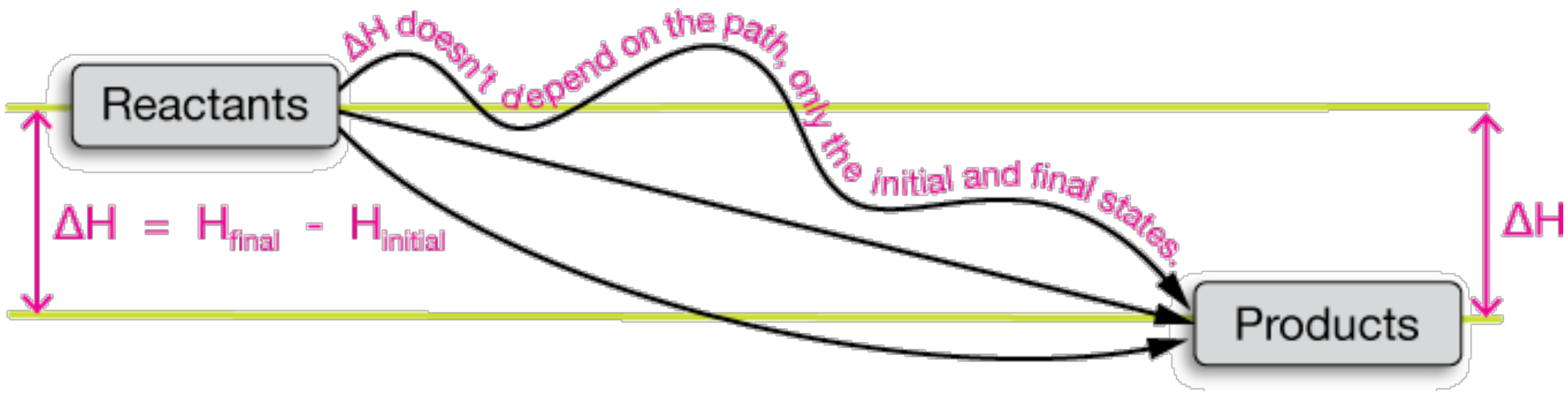
$$A + B \rightarrow C + D$$

For a particular chemical reaction (above), we can use any of the following methods to calculate the ΔH_{rxn}:

- Calorimetry: measure the heat absorbed (q_{abs}) by surrounding water, where $q_{abs} = -\Delta H_{rxn}$
- Use the standards heats of formations: $\Delta H_{\text{rxn}} = \sum n_{\text{products}} \Delta H^{\text{o}}_{\text{f,products}} - \sum n_{\text{reactants}} \Delta H^{\text{o}}_{\text{f,reactants}}$
- Apply Hess's Law on related chemical reactions with known ΔH_{rxn}

Review: Heats of Reactions (Δ*H*)

Remember that enthalpy is a state function, so we only care about the difference between the final state and the initial state.



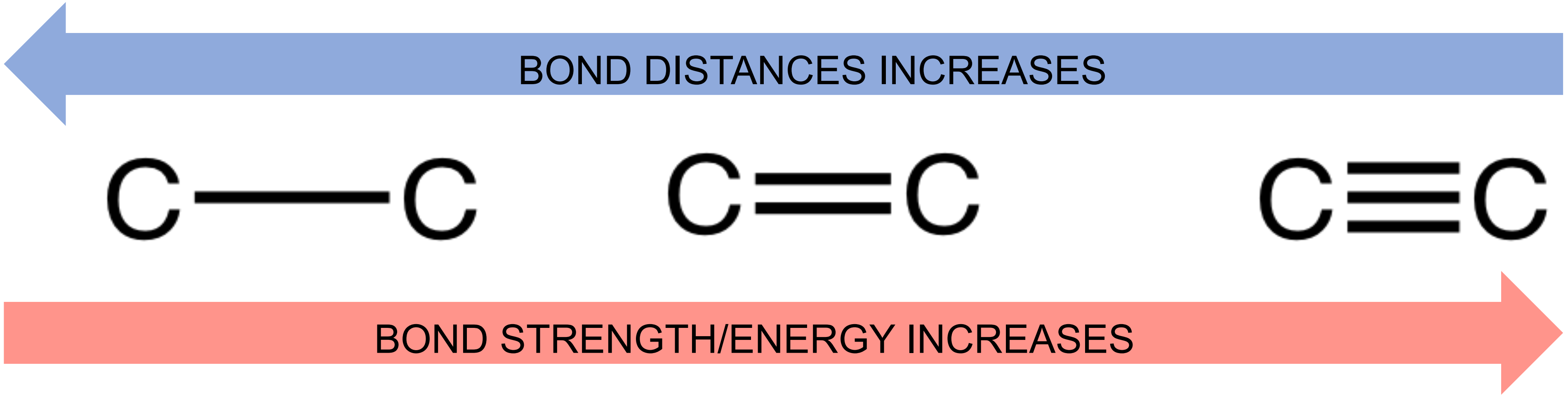
A + B → C + D

For a particular chemical reaction (above), we can use any of the following methods to calculate the ΔH_{rxn}:

- Calorimetry: measure the heat absorbed (q_{abs}) by surrounding water, where $q_{abs} = -\Delta H_{rxn}$
- Use the standards heats of formations: $\Delta H_{\text{rxn}} = \sum n_{\text{products}} \Delta H^{\text{o}}_{\text{f,products}} - \sum n_{\text{reactants}} \Delta H^{\text{o}}_{\text{f,reactants}}$
- Apply Hess's Law on related chemical reactions with known ΔH_{rxn}
- Estimate using bond enthalpies (Δ*H*) for bonds broken and bonds formed during the reaction

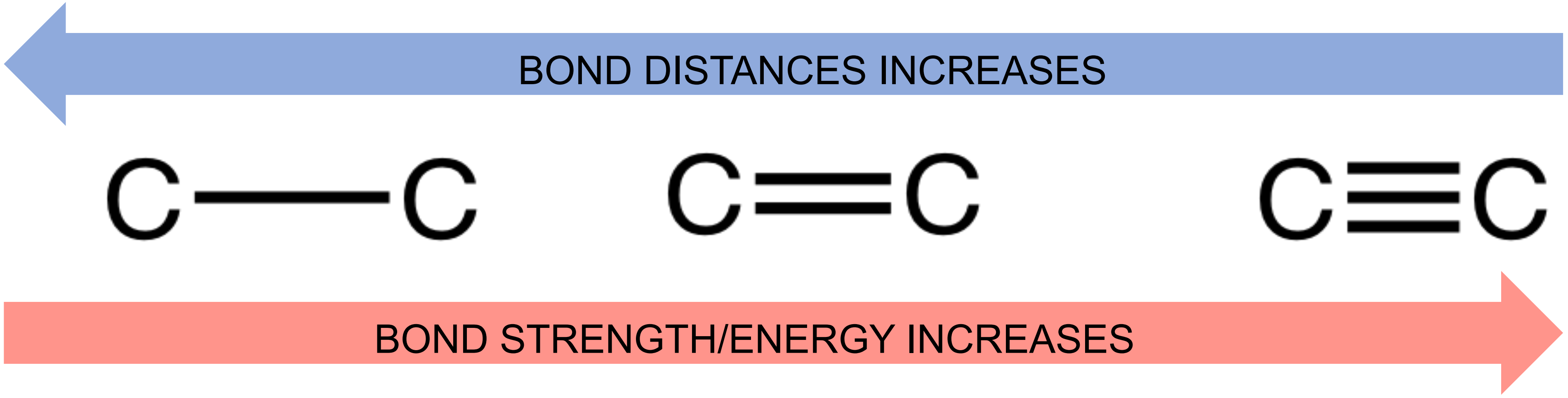
Bond Type, Bond Length, and Bond Strength

Using the example of different carbon-carbon bonds, the following trend is generally true:



Bond Type, Bond Length, and Bond Strength

Using the example of different carbon-carbon bonds, the following trend is generally true:

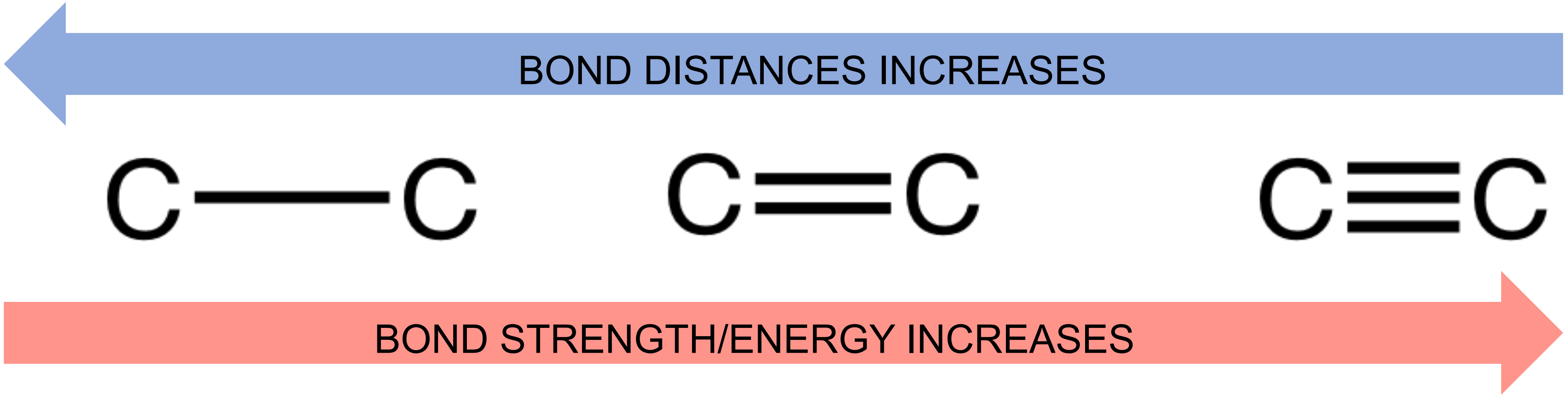


BREAKING BONDS → ENDOTHERMIC: requires energy to *break* bonds

FORMING BONDS → EXOTHERMIC: releases energy to *form* bonds

Bond Type, Bond Length, and Bond Strength

Using the example of different carbon-carbon bonds, the following trend is generally true:



BREAKING BONDS → ENDOTHERMIC: requires energy to *break* bonds

FORMING BONDS → EXOTHERMIC: releases energy to *form* bonds

$$\Delta H_{\text{rxn}} \approx \sum \Delta H(\text{bonds broken in reactants}) - \sum \Delta H(\text{bonds formed in products})$$

By definition, all bond enthalpies are positive values.

Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

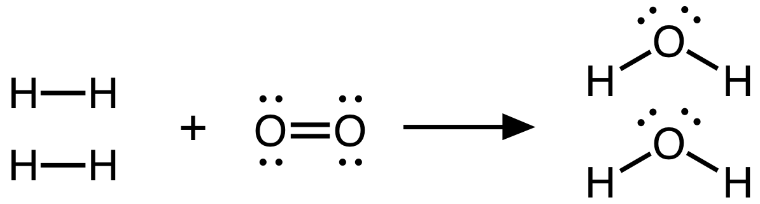
Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

- Draw out the Lewis structures of reactants and products



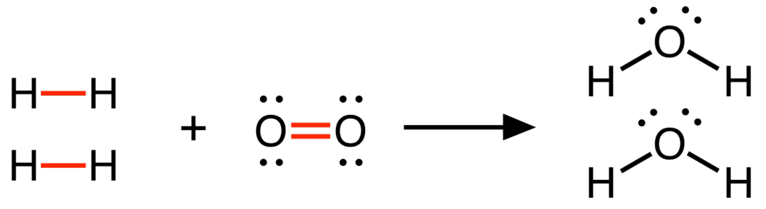
Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C═C	134	614	O—O	148	146
C≡C	120	839	O═O	121	495
C—N	147	293	O—H	96	463
C═N	127	615	S—O	151	265
C≡N	116	891	S═O	143	523
C—O	143	358	S—S	204	266
C═O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N═N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N═O	122	607			

[a]The bond energy of the C═O bond in CO_2 is 799 kJ/mol.

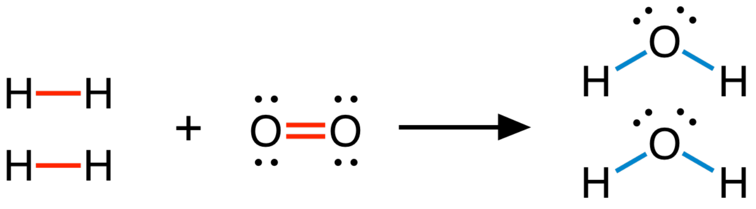
Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607			

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

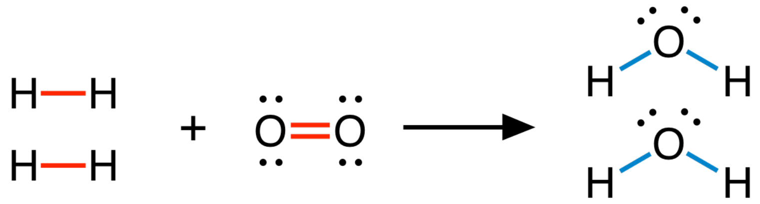
Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.
- Set up expression for ΔH_{rxn}:

$$\Delta H_{\mathrm{rxn}} \approx \sum \Delta H \begin{pmatrix}\text{bonds broken} \\ \text{in reactants}\end{pmatrix} - \sum \Delta H \begin{pmatrix}\text{bonds formed} \\ \text{in products}\end{pmatrix}$$

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607			

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

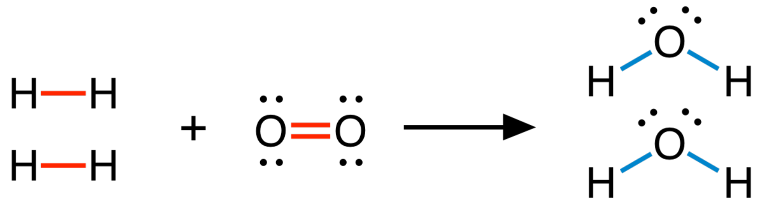
Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$2\,H_2\,(g) + O_2\,(g) \rightarrow 2\,H_2O\,(g)$$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.
- Set up expression for ΔH_{rxn}:

$$\Delta H_{rxn} \approx \sum \Delta H \begin{pmatrix}\text{bonds broken} \\ \text{in reactants}\end{pmatrix} - \sum \Delta H \begin{pmatrix}\text{bonds formed} \\ \text{in products}\end{pmatrix}$$

$$= (2\text{ mol} \times \Delta H_{H-H}) + (1\text{ mol} \times \Delta H_{O=O}) - (4\text{ mol} \times \Delta H_{O-H})$$

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607			

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

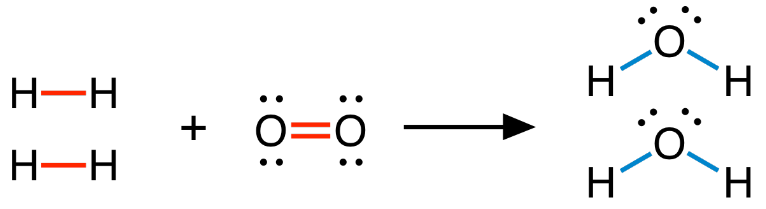
Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.
- Set up expression for ΔH_{rxn}:

$$\Delta H_{rxn} \approx \sum \Delta H \begin{pmatrix}\text{bonds broken}\\ \text{in reactants}\end{pmatrix} - \sum \Delta H \begin{pmatrix}\text{bonds formed}\\ \text{in products}\end{pmatrix}$$

$$= (2\text{ mol} \times \Delta H_{H-H}) + (1\text{ mol} \times \Delta H_{O=O}) - (4\text{ mol} \times \Delta H_{O-H})$$

$$= \left(2\text{ mol} \times 436 \tfrac{\text{kJ}}{\text{mol}}\right) + \left(1\text{ mol} \times 495 \tfrac{\text{kJ}}{\text{mol}}\right) - \left(4\text{ mol} \times 463 \tfrac{\text{kJ}}{\text{mol}}\right)$$

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C═C	134	614	O—O	148	146
C≡C	120	839	O═O	121	495
C—N	147	293	O—H	96	463
C═N	127	615	S—O	151	265
C≡N	116	891	S═O	143	523
C—O	143	358	S—S	204	266
C═O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N═N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N═O	122	607			

[a] The bond energy of the C═O bond in CO_2 is 799 kJ/mol.

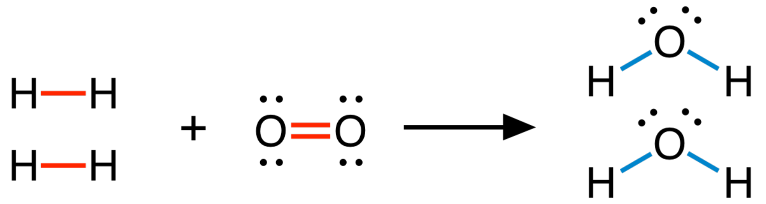
Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.
- Set up expression for ΔH_{rxn}:

$$\Delta H_{\text{rxn}} \approx \sum \Delta H \begin{pmatrix}\text{bonds broken} \\ \text{in reactants}\end{pmatrix} - \sum \Delta H \begin{pmatrix}\text{bonds formed} \\ \text{in products}\end{pmatrix}$$

$$= (2\text{ mol} \times \Delta H_{\text{H-H}}) + (1\text{ mol} \times \Delta H_{\text{O=O}}) - (4\text{ mol} \times \Delta H_{\text{O-H}})$$

$$= \left(2\text{ mol} \times 436\frac{\text{kJ}}{\text{mol}}\right) + \left(1\text{ mol} \times 495\frac{\text{kJ}}{\text{mol}}\right) - \left(4\text{ mol} \times 463\frac{\text{kJ}}{\text{mol}}\right)$$

$$\Delta H_{\text{rxn}} \approx -485\text{ kJ}$$

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607			

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

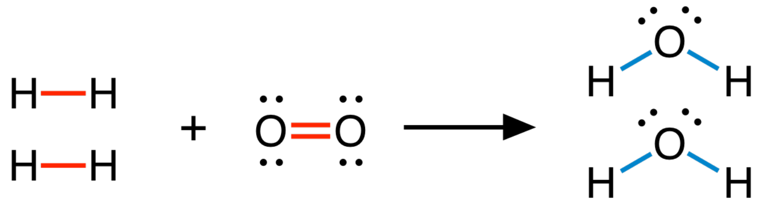
Bond Enthalpies

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.
- Set up expression for ΔH_{rxn}:

$$\Delta H_{rxn} \approx \sum \Delta H \begin{pmatrix}\text{bonds broken} \\ \text{in reactants}\end{pmatrix} - \sum \Delta H \begin{pmatrix}\text{bonds formed} \\ \text{in products}\end{pmatrix}$$

$$= (2\ \text{mol} \times \Delta H_{H-H}) + (1\ \text{mol} \times \Delta H_{O=O}) - (4\ \text{mol} \times \Delta H_{O-H})$$

$$= \left(2\ \text{mol} \times 436 \frac{\text{kJ}}{\text{mol}}\right) + \left(1\ \text{mol} \times 495 \frac{\text{kJ}}{\text{mol}}\right) - \left(4\ \text{mol} \times 463 \frac{\text{kJ}}{\text{mol}}\right)$$

$$\Delta H_{rxn} \approx -485\ \text{kJ}$$

As a double-check, the standard heat of formation of H_2O (*g*) is $\Delta H_f^o = -241.8\ \frac{\text{kJ}}{\text{mol}}$.

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607			

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

A more interesting example:

Previously, we used Hess's Law to find ΔH_{rxn}

Let's say you want to calculate the heat of reaction for the following reaction:

$$ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$$

You have access to the heats of reactions of some related reactions:

(1)	$2OF_2\ (g) \rightarrow O_2\ (g) + 2F_2\ (g)$	ΔH = –49.4 kJ
(2)	$2ClF\ (g) + O_2\ (g) \rightarrow Cl_2O\ (g) + OF_2\ (g)$	ΔH = +205.6 kJ
(3)	$ClF_3\ (g) + O_2\ (g) \rightarrow 1/2\ Cl_2O\ (g) + 3/2\ OF_2\ (g)$	ΔH = +266.7 kJ

Now sum up reactions (2), (1), and (3):

(2)	$ClF\ (g) + ½\ O_2\ (g) \rightarrow ½\ Cl_2O\ (g) + ½\ OF_2\ (g)$	ΔH = ½ (+205.6 kJ)
(1)	$F_2\ (g) + ½\ O_2\ (g) \rightarrow OF_2\ (g)$	ΔH = ½ (+49.4 kJ)
(3)	$1/2\ Cl_2O\ (g) + 3/2\ OF_2\ (g) \rightarrow ClF_3\ (g) + O_2\ (g)$	ΔH = –266.7 kJ
	$ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$	ΔH_{rxn} = –139.2 kJ

CAN WE USE BOND ENTHALPIES INSTEAD?

Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$$

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C═C	134	614	O—O	148	146
C≡C	120	839	O═O	121	495
C—N	147	293	O—H	96	463
C═N	127	615	S—O	151	265
C≡N	116	891	S═O	143	523
C—O	143	358	S—S	204	266
C═O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N═N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N═O	122	607	Cl—F		256

[a]The bond energy of the C═O bond in CO_2 is 799 kJ/mol.

Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$

- Draw out the Lewis structures of reactants and products

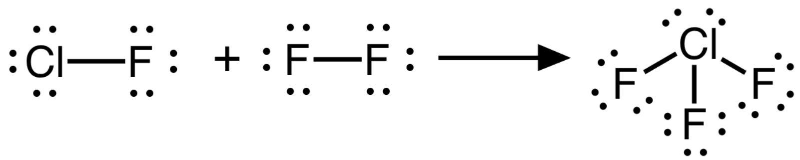


TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C═C	134	614	O—O	148	146
C≡C	120	839	O═O	121	495
C—N	147	293	O—H	96	463
C═N	127	615	S—O	151	265
C≡N	116	891	S═O	143	523
C—O	143	358	S—S	204	266
C═O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N═N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N═O	122	607	Cl—F		256

[a]The bond energy of the C═O bond in CO_2 is 799 kJ/mol.

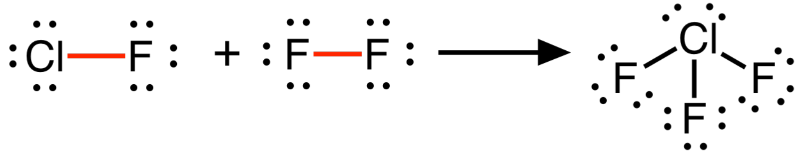
Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $ClF (g) + F_2 (g) \rightarrow ClF_3 (g)$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C═C	134	614	O—O	148	146
C≡C	120	839	O═O	121	495
C—N	147	293	O—H	96	463
C═N	127	615	S—O	151	265
C≡N	116	891	S═O	143	523
C—O	143	358	S—S	204	266
C═O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N═N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N═O	122	607	Cl—F		256

[a]The bond energy of the C═O bond in CO_2 is 799 kJ/mol.

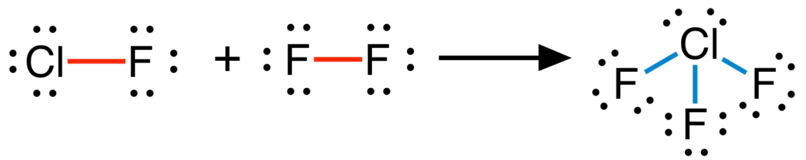
Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

$$ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607	Cl—F		256

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

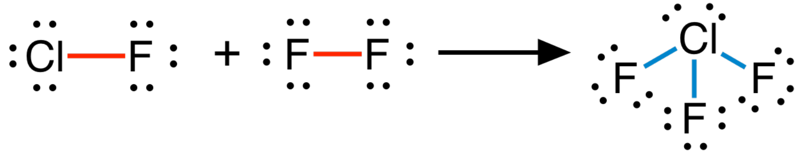
Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.

Q: Did we really need to break the Cl–F bond in the reactants?

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607	Cl—F		256

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

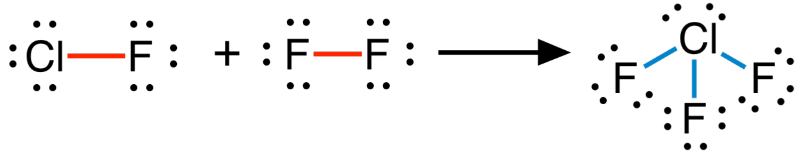
Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.

Q: Did we really need to break the Cl–F bond in the reactants?
A: No, we just need to form two more Cl–F bonds in the products.

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607	Cl—F		256

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

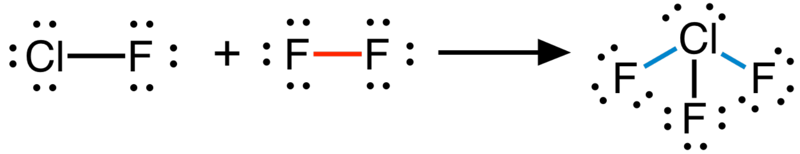
Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.

Q: Did we really need to break the Cl–F bond in the reactants?
A: No, we just need to form two more Cl–F bonds in the products.

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607	Cl—F		256

[a] The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

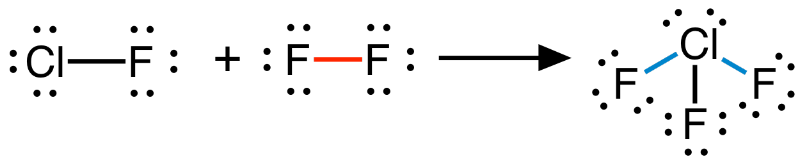
Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.

Q: Did we really need to break the Cl–F bond in the reactants?
A: No, we just need to form two more Cl–F bonds in the products.

$$\Delta H_{rxn} \approx \sum \Delta H \begin{pmatrix}\text{bonds broken} \\ \text{in reactants}\end{pmatrix} - \sum \Delta H \begin{pmatrix}\text{bonds formed} \\ \text{in products}\end{pmatrix}$$

$$= (1\text{ mol} \times \Delta H_{F-F}) - (2\text{ mol} \times \Delta H_{Cl-F})$$

$$= \left(1\text{ mol} \times 155\,\tfrac{\text{kJ}}{\text{mol}}\right) - \left(2\text{ mol} \times 256\,\tfrac{\text{kJ}}{\text{mol}}\right)$$

$$\Delta H_{rxn} \approx -357\text{ kJ}$$

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607	Cl—F		256

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

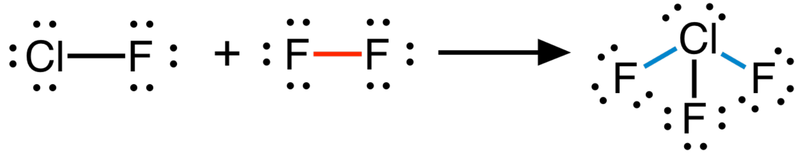
Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $ClF\ (g) + F_2\ (g) \rightarrow ClF_3\ (g)$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.

Q: Did we really need to break the Cl–F bond in the reactants?
A: No, we just need to form two more Cl–F bonds in the products.

$$\Delta H_{\text{rxn}} \approx \sum \Delta H \begin{pmatrix}\text{bonds broken} \\ \text{in reactants}\end{pmatrix} - \sum \Delta H \begin{pmatrix}\text{bonds formed} \\ \text{in products}\end{pmatrix}$$

$$= (1\ \text{mol} \times \Delta H_{\text{F-F}}) - (2\ \text{mol} \times \Delta H_{\text{Cl-F}})$$

$$= \left(1\ \text{mol} \times 155\ \frac{\text{kJ}}{\text{mol}}\right) - \left(2\ \text{mol} \times 256\ \frac{\text{kJ}}{\text{mol}}\right)$$

$$\Delta H_{\text{rxn}} \approx -357\ \text{kJ}$$

From Hess's Law $\Delta H_{\text{rxn}} = -139.2\ \text{kJ}$.

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C=C	134	614	O—O	148	146
C≡C	120	839	O=O	121	495
C—N	147	293	O—H	96	463
C=N	127	615	S—O	151	265
C≡N	116	891	S=O	143	523
C—O	143	358	S—S	204	266
C=O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N=N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N=O	122	607	Cl—F		256

[a]The bond energy of the C=O bond in CO_2 is 799 kJ/mol.

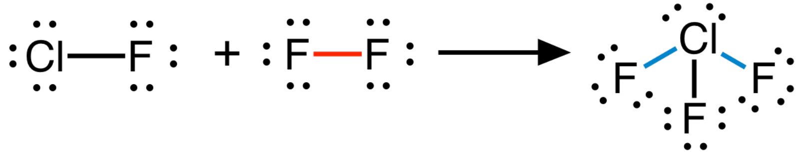
Example: ClF_3 (*g*)

In order to estimate the heat of a reaction (ΔH_{rxn}), you need to:

- Balance the chemical equation

  $ClF(g) + F_2(g) \rightarrow ClF_3(g)$

- Draw out the Lewis structures of reactants and products



- Be given bond enthalpies for bonds broken in reactants.
- Be given bond enthalpies for bonds formed in products.

Q: Did we really need to break the Cl–F bond in the reactants?
A: No, we just need to form two more Cl–F bonds in the products.

$$\Delta H_{rxn} \approx \sum \Delta H \begin{pmatrix}\text{bonds broken}\\ \text{in reactants}\end{pmatrix} - \sum \Delta H \begin{pmatrix}\text{bonds formed}\\ \text{in products}\end{pmatrix}$$

$$= (1\ \text{mol} \times \Delta H_{F-F}) - (2\ \text{mol} \times \Delta H_{Cl-F})$$

$$= \left(1\ \text{mol} \times 155\ \frac{\text{kJ}}{\text{mol}}\right) - \left(2\ \text{mol} \times 256\ \frac{\text{kJ}}{\text{mol}}\right)$$

$$\Delta H_{rxn} \approx -357\ \text{kJ}$$

From Hess's Law $\Delta H_{rxn} = -139.2\ \text{kJ}$.
So what happened? Bond enthalpies are averaged, so they aren't the most accurate!

TABLE 8.3 Selected Average Covalent Bond Lengths and Bond Energies

Bond	Bond Length (pm)	Bond Energy (kJ/mol)	Bond	Bond Length (pm)	Bond Energy (kJ/mol)
C—C	154	348	N≡O	106	678
C═C	134	614	O—O	148	146
C≡C	120	839	O═O	121	495
C—N	147	293	O—H	96	463
C═N	127	615	S—O	151	265
C≡N	116	891	S═O	143	523
C—O	143	358	S—S	204	266
C═O	123	743[a]	S—H	134	347
C≡O	113	1072	H—H	75	436
C—H	110	413	H—F	92	567
C—F	133	485	H—Cl	127	431
C—Cl	177	328	H—Br	141	366
N—H	104	388	H—I	161	299
N—N	147	163	F—F	143	155
N═N	124	418	Cl—Cl	200	243
N≡N	110	941	Br—Br	228	193
N—O	136	201	I—I	266	151
N═O	122	607	Cl—F		256

[a]The bond energy of the C═O bond in CO_2 is 799 kJ/mol.