

$$\Delta H_{rxn} = \sum \Delta H_{bonds\ broken} - \sum \Delta H_{bonds\ formed}$$

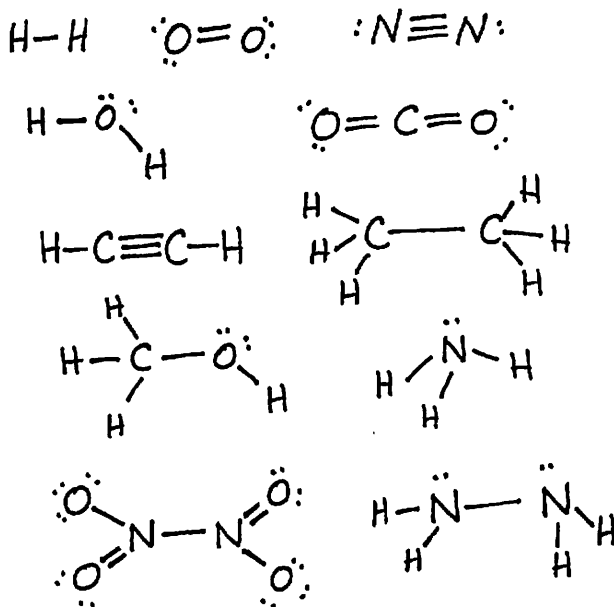
The ΔH of a reaction can be estimated* using average bond enthalpies (aka "bond dissociation energies").

The bond enthalpy (" ΔH_{bond} ") is the energy required to break a bond.
It is usually reported in kJ/mole (kJ energy required to break 1 mole of bonds).

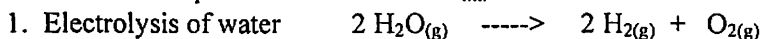
* the calculation is only an estimation, since you are using average bond energies; not all C-C, H-O, C=O, etc. bonds require the same energy to break. Also, this method is less accurate when non-gases (solids and liquids) are reacting, since solids and liquids not only have bonds within molecules; they also have intermolecular attractive forces, which require energy to overcome.

Average Bond Enthalpies/Bond Dissociation Energies (kJ/mole)

Single Bonds							
C-H	413	N-H	391	O-H	463	F-F	155
C-C	348	N-N	163	O-O	146	Cl-F	253
C-N	293	N-O	201	O-F	190	Cl-Cl	242
C-O	358	N-F	272	O-Cl	203	Br-F	237
C-F	485	N-Cl	200	O-I	234	Br-Cl	218
C-Cl	328	N-Br	243			Br-Br	193
C-Br	276			S-H	339		
C-I	240	H-H	436	S-F	327		
C-S	259	H-F	567	S-Cl	253	I-Cl	208
		H-Cl	431	S-Br	218	I-Br	175
Si-H	323	H-Br	366	S-S	266	I-I	151
Si-Si	226	H-I	299				
Si-C	301						
Si-O	368						
Si-Cl	464						
Multiple Bonds							
C=C	614	N=N	418	O ₂	495		
C≡C	839	N≡N	941	S=O	523		
C=N	615	N=O	607	S=S	418		
C≡N	891						
C=O	799						
C≡O	1072						



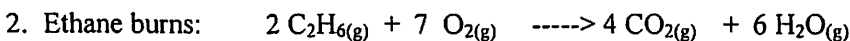
Use bond enthalpies to estimate the ΔH_{rxn} for each reaction:



Broken: $4(\text{H-O}) = 4(463\text{ kJ}) = 1852\text{ kJ}$ ← total energy required/absorbed in breaking bonds

Formed: $2(\text{H-H}) = 2(436\text{ kJ}) = 872\text{ kJ}$
 $1(\text{O=O}) = 1(495\text{ kJ}) = 495\text{ kJ}$ > total energy released in forming new bonds: 1367 kJ

Broken - Formed = $1852\text{ kJ} - 1367\text{ kJ} = \boxed{\Delta H_{rxn} = 485\text{ kJ}}$



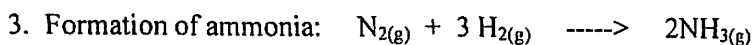
Broken

$2(\text{C-C})\text{ bonds} = 2(348\text{ kJ}) = 696\text{ kJ}$
 $12(\text{C-H})\text{ bonds} = 12(413\text{ kJ}) = 4956\text{ kJ}$
 $7(\text{O=O})\text{ bonds} = 7(495\text{ kJ}) = 3465\text{ kJ}$
 total: 9117 kJ

Formed

$8(\text{C=O}) = 8(799\text{ kJ}) = 6392\text{ kJ}$
 $12(\text{H-O}) = 12(463\text{ kJ}) = 5556\text{ kJ}$
 total: 11948 kJ

$9117\text{ kJ} - 11948\text{ kJ} = \boxed{-2831\text{ kJ} = \Delta H_{rxn}}$



Broken

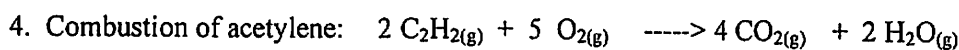
$$1 (N \equiv N) = 1(941) = 941 \text{ kJ}$$

$$3 (H-H) = 3(436 \text{ kJ}) = 1308 \text{ kJ}$$

total: $\underline{2249 \text{ kJ}}$

Formed: $6 (N-H) = 6(391 \text{ kJ})$
 $= \underline{2346 \text{ kJ}}$

$$2249 - 2346 = \boxed{-97 \text{ kJ}}$$



Broken:

$$2 (C \equiv C) = 2(839) = 1678 \text{ kJ}$$

$$4 (C-H) = 4(413) = 1652 \text{ kJ}$$

$$5 (O=O) = 5(495) = 2475 \text{ kJ}$$

Total: $\underline{5805 \text{ kJ}}$

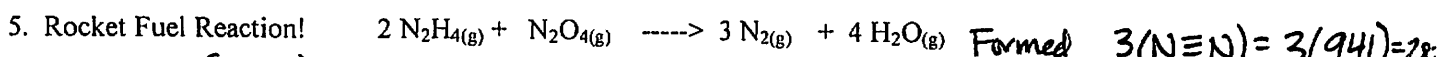
Formed:

$$8 (C=O) = 8(799) = 6392 \text{ kJ}$$

$$4 (H-O) = 4(463) = 1852 \text{ kJ}$$

Total: $\underline{8244 \text{ kJ}}$

$$5805 \text{ kJ} - 8244 \text{ kJ} = \boxed{-2439 \text{ kJ}}$$



Broken

$$3 (N-N) = 3(163) = 489$$

$$8 (N-H) = 8(391) = 3128$$

$$1 (N-N) = 1(941) = 941$$

$$2 (N=O) = 2(607) = 1214$$

$$2 (N-O) = 2(201) = 402$$

total: $\underline{5233 \text{ kJ}}$

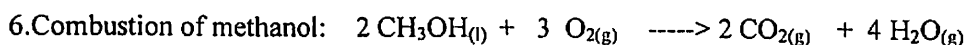
Formed

$$3 (N \equiv N) = 3(941) = 2823$$

$$8 (H-O) = 8(463) = 3704$$

total: $\underline{6527 \text{ kJ}}$

$$5233 \text{ kJ} - 6527 \text{ kJ} = \boxed{-1294 \text{ kJ}}$$



Broken

$$2 (C-O) = 2(358) = 716$$

$$6 (C-H) = 6(413) = 2478$$

$$2 (O-H) = 2(463) = 926$$

$$3 (O=O) = 3(495) = 1485$$

$\underline{5605 \text{ kJ}}$

Formed

$$4 (C=O) = 4(799) = 3196$$

$$8 (H-O) = 8(463) = 3704$$

$\underline{6900 \text{ kJ}}$

$$5605 \text{ kJ} - 6900 \text{ kJ} = \boxed{-1295 \text{ kJ}}$$

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Single Bonds			
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Si-Cl	464	H-I	299
O-H	463	O-O	146
O-F	190	O-F	190
O-Cl	203	O-Cl	203
O-I	234	O-I	234
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Br-Cl	218	I-Cl	208
Br-Br	193	I-Br	175
I-Cl	208	I-I	151
I-Br	175		
I-I	151		

Multiple Bonds			
C=C	614	N=N	418
C≡C	839	N≡N	941
C=N	615	N=O	607
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C=O	799	S=S	418
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