

Student Name: _____ TF's name: _____ Discussion Day/Time: _____

Things you should know when you leave Discussion today:

- Enthalpy of the reaction $\Delta_{\text{rxn}}H^\circ$, Mahaffy, 2e section 7.6
 - Standard Molar Enthalpy of Formation (Δ_fH°) Mahaffy, 2e section 7.8
 - Calculating Δ_rH° of the reaction by using Enthalpy of Formation Δ_fH°
- Calculating $\Delta_{\text{rxn}}H^\circ$ Enthalpy of the reaction by using Bond Enthalpy Δ_BH Mahaffy, 2e section 7.9
- Hess' Law, Mahaffy, 2e section 7.7
- Energy diagrams change of state, Mahaffy, 2e section 7.5
- In preparation for next week: Hydrogen atom family album, PDF, 7 pages, <http://goo.gl/XPkcxv>
 - <http://quantum.bu.edu/notes/GeneralChemistry/OneElectronOrbitalTomography.html>
 - Glossary of electron waves in atoms, PDF, 1 pages, <http://goo.gl/oACWb1>

1. Define the Standard Enthalpy of Formation (Δ_fH°) then choose one below.

always positive

never positive

sometimes positive

- a. Is it possible for Standard Enthalpy of Formation (Δ_fH°) = 0? (If so, explain when.)
2. Write the chemical equation whose enthalpy change is equal exactly to the standard enthalpy of formation, Δ_fH° , of solid urea. ($\Delta_fH^\circ(\text{H}_2\text{NCONH}_2(\text{s})) = -632\text{kJ/mol}$).
- a. Draw the energy diagram representation of the reaction in first part of the problem.
Hint: remember you need to identify your reactant and your products.

3. Calculate the heat of combustion of 132.0g of propane, C_3H_8 (l), in excess oxygen using the following approximate enthalpies of formation: $\Delta_fH^\circ(\text{C}_3\text{H}_8(\text{l})) = -104.7\text{kJ/mol}$, $\Delta_fH^\circ(\text{CO}_2(\text{g})) = -393.5\text{kJ/mol}$, $\Delta_fH^\circ(\text{H}_2\text{O}(\text{g})) = -241.8\text{kJ/mol}$.

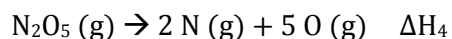
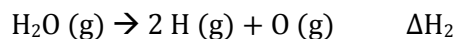
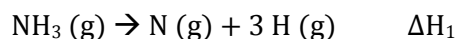
Hint: Start with writing the balanced chemical reaction.

Using **Standard Enthalpy of Formation (Δ_fH°)** for calculating enthalpy of reactions Δ_rH°

$$\Delta_{\text{rxn}}H^\circ = \sum_{\text{products}} n_{\text{product}} (\Delta_fH^\circ) - \sum_{\text{reactants}} n_{\text{reactant}} (\Delta_fH^\circ) = \Delta H_{\text{final}} - \Delta H_{\text{initial}} = \text{products} - \text{reactants}$$

- a. Calculate the heat of combustion if reaction only preceded 75%.
Hint: Heat (q) equals $\Delta_{rxn}H^\circ$ times the number of moles of reaction.

4. An atomization reaction breaks a compound apart into its gaseous atoms. Use the following atomization reactions and their enthalpies of atomization to *obtain the expression* for the enthalpy change of the reaction, $\Delta_{rxn}H$, in terms of ΔH_1 , ΔH_2 , ΔH_3 , and ΔH_4 for the combustion of one mole of gaseous ammonia to yield gaseous water and dinitrogen pentoxide, N_2O_5 (g).



Using Bond Enthalpy ($\Delta_B H$) for to calculate the $\Delta_r H$ of the reaction:

$$\Delta_{rxn}H^\circ = \sum \Delta_B H(\text{broken}) - \sum \Delta_B H(\text{formed})$$

5. Define the Bond Enthalpy ($\Delta_B H$) and choose one of choices below:

Always positive

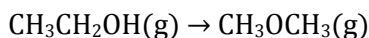
Never positive

Sometimes positive

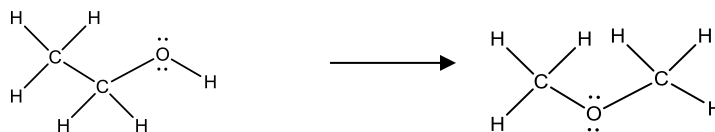
- a. Draw the energy diagram representation for bond energy:

6. Ethanol, $CH_3CH_2OH(g)$, and dimethyl ether, $CH_3OCH_3(g)$ are structural isomers.

- a. Estimate the enthalpy of reaction ($\Delta_r H$) of the given reaction using the provided bond enthalpies.



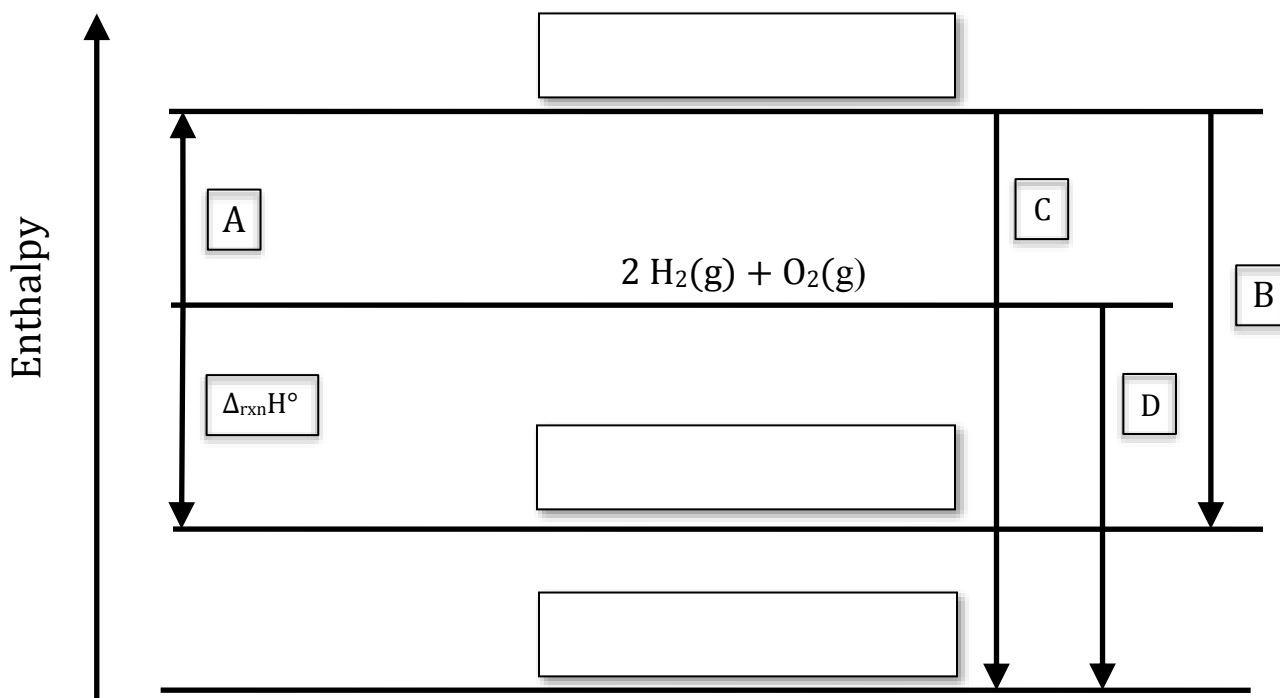
Bond	O-H	C-H	C-O	C-C	O=O	C=O
$\Delta_B H(\text{kJ/mol})$	460.	410.	350.	350.	500.	750.



- a. Calculate the enthalpy of reaction ($\Delta_r H$) using enthalpy of formations. (Ethanol, $\text{CH}_3\text{CH}_2\text{OH}(\text{l})$; $\Delta H_f^\circ = -277 \text{ kJ/mol}$) and dimethyl ether, ($\text{CH}_3\text{OCH}_3(\text{g})$; $\Delta H_f^\circ = -184. \text{ kJ/mol}$) Compare the bond enthalpy estimate to the enthalpy of formation value.

7. An enthalpy diagram of hydrogen gas combusting to form gaseous water is shown below.

- a. Write down balanced chemical reaction for this process:
- b. Fill in the horizontal lines using only the following species and corresponding coefficients in the appropriate boxes: $\text{H}(\text{g})$, $\text{O}(\text{g})$, and $\text{H}_2\text{O}(\text{g})$, $\text{H}_2\text{O}(\text{l})$.



- c. For the labeled arrows on the diagram above, write the expression for the enthalpy change in terms of bond enthalpies and enthalpies of formation and enthalpy of vaporization.

A: _____

B: _____

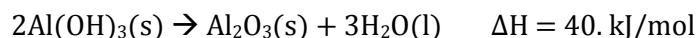
C: _____

D: _____

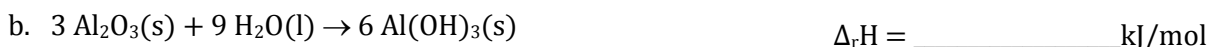
- d. Estimate the value of $\Delta_r H$ of the reaction above, in terms of the molar bond enthalpies $\Delta_b H(\text{H}-\text{H}) = 440.0 \text{ kJ/mol}$; $\Delta_b H(\text{C}-\text{H}) = 410.0 \text{ kJ/mol}$; $\Delta_b H(\text{O}=\text{O}) = 500.0 \text{ kJ/mol}$; $\Delta_b H(\text{O}-\text{H}) = 450.0 \text{ kJ/mol}$.

8. A 100. mL sample of 0.20 M HCl is mixed with 100. mL of 0.30 M NaOH in a calorimeter. Both solutions start at 22.50°C and, after mixing, the temperature rises to 23.50°C. Assuming that the calorimeter does not absorb any heat and that the solutions have the same heat capacity and density as pure water, what is the molar enthalpy of neutralization of the acid?

9. A chemist measures the enthalpy change ΔH during the following reaction:



Use this information to determine the $\Delta_r H$ for the following reactions:



- c. 4 moles of $\text{Al}_2\text{O}_3(\text{s})$ are reacted with 6 moles of $\text{H}_2\text{O}(\text{l})$ with 75% yield.

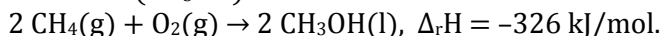
$$q_P = \underline{\hspace{2cm}} \text{ kJ}$$

- d. When 3 moles of $\text{Al}(\text{OH})_3(\text{s})$ reacts with 100% yield.

$$\Delta_r H = \underline{\hspace{2cm}} \text{ kJ/mol}$$

$$q_P = \underline{\hspace{2cm}} \text{ kJ}$$

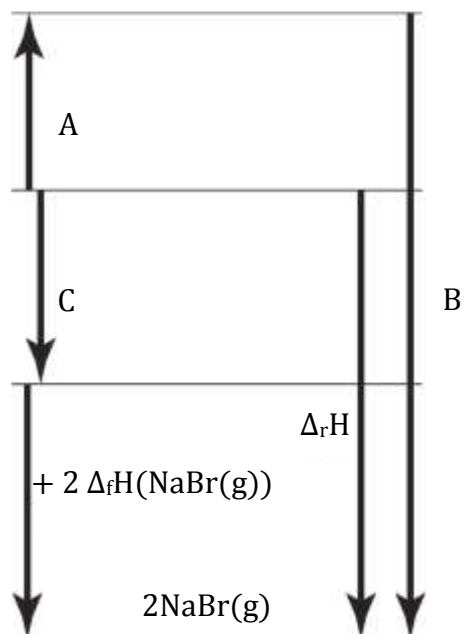
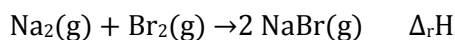
10. Consider the following reaction for the oxidation of methane (CH_4) to methanol (CH_3OH):



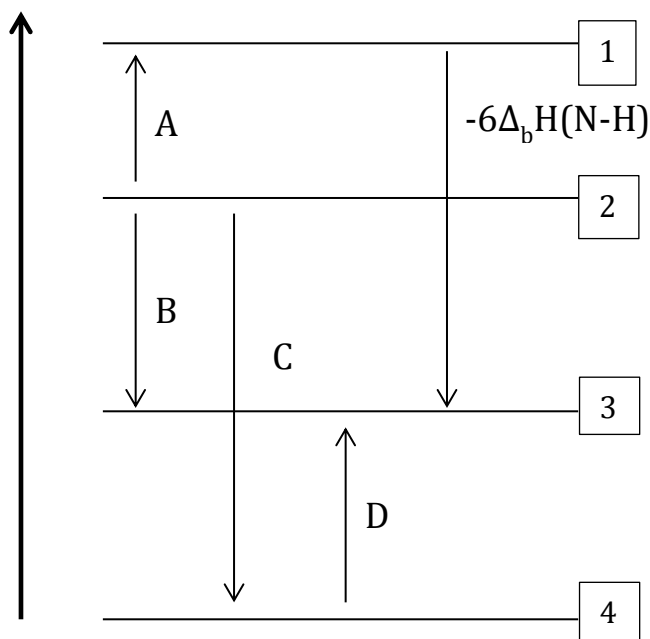
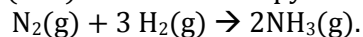
- a. Use the following bond enthalpies, and the enthalpy of reaction above, to calculate the enthalpy of vaporization of methanol (in kJ/mol). Data: $\Delta_b H(\text{C-H}) = 413 \text{ kJ/mol}$, $\Delta_b H(\text{C-C}) = 346 \text{ kJ/mol}$, $\Delta_b H(\text{C-O}) = 358 \text{ kJ/mol}$, $\Delta_b H(\text{O-H}) = 463 \text{ kJ/mol}$, $\Delta_b H(\text{H-H}) = 436 \text{ kJ/mol}$, and $\Delta_b H(\text{O=O}) = 498 \text{ kJ/mol}$.

$$\Delta_{\text{vap}} H(\text{CH}_3\text{OH}) = \underline{\hspace{2cm}} \text{ kJ/mol}$$

11. (As seen in lecture) The enthalpy change of formation of NaBr(g) is $\Delta_f H = -143 \text{ kJ}$. Complete the enthalpy diagram on the right, by labeling the three horizontal lines with the corresponding species and by labeling the three vertical arrows with the corresponding enthalpy change. Possible species to use in labels of the horizontal lines are Na(s) , Na(g) , $\text{Na}_2(\text{g})$, $\text{Br}_2(\text{l})$, Br(g) and $\text{Br}_2(\text{g})$. The labels of the vertical arrows consist of various enthalpies of formation, $\Delta_f H$, and bond enthalpies, $\Delta_b H$.

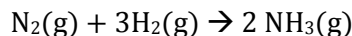


12. Consider the enthalpy change diagram below. Label horizontal lines with the substances involved in the chemical equation, then label the remaining lines with appropriate species. Write an expression for each labeled arrow (A-D) with the enthalpy change it corresponds to.



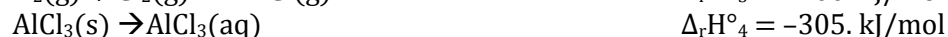
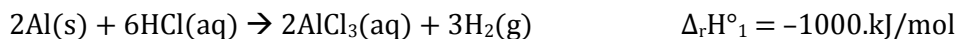
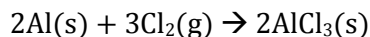
13. When 1.00L of 2.00M Na₂SO₄ solution at 30.0°C is added to 2.00L of 0.75M Ba(NO₃)₂ solution at 30.0°C in a calorimeter, a white solid forms and the temperature of the final solution is 45.0°C. Assuming that the specific heat capacity of the solution is 6.00 J/(K·g) and that the density of the solution is 2.00g/ml calculate the enthalpy change (in kJ/mole) of BaSO₄ formed.

14. Consider the following chemical reaction:



What is the $\Delta_{\text{rxn}}H$ and q_{rxn} when 0.28 g of N₂ and 1.8 g of H₂ react? ($\Delta_f H^\circ(\text{NH}_3(\text{g})) = -46 \text{ kJ/mol}$)

15. Using the following information for:



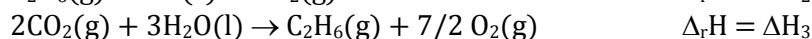
a. Calculate $\Delta_r H$ using (all values in kJ/mol)

b. When 1.35g of Al(s) reacts with 0.710g of Cl₂(g), 250. J of work is done. What is q_v for this reaction in kJ?

16. Calculate the standard enthalpy of formation $\Delta_f H^\circ$ of Co₃O₄(s) from the following information.



17. Give the expression for the enthalpy of formation, $\Delta_f H$, of CO₂(g) in terms of ΔH_1 , ΔH_2 , and ΔH_3 .

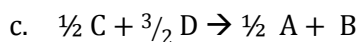


18. The enthalpy of neutralization for the reaction of strong acid with strong base is $-60. \text{kJ/mol}$ water produced. How much energy (in kJ) will be released when 200.0 mL of 0.400M HCl is mixed with and 150.0 mL of 0.500M NaOH?

19. Consider the following generic chemical reactions.

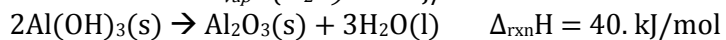


Determine the value of $\Delta H^\circ_{\text{rxn}}$ for the following related reactions.

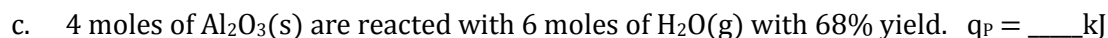


20. A chemist measures the enthalpy change ΔH during the following reaction

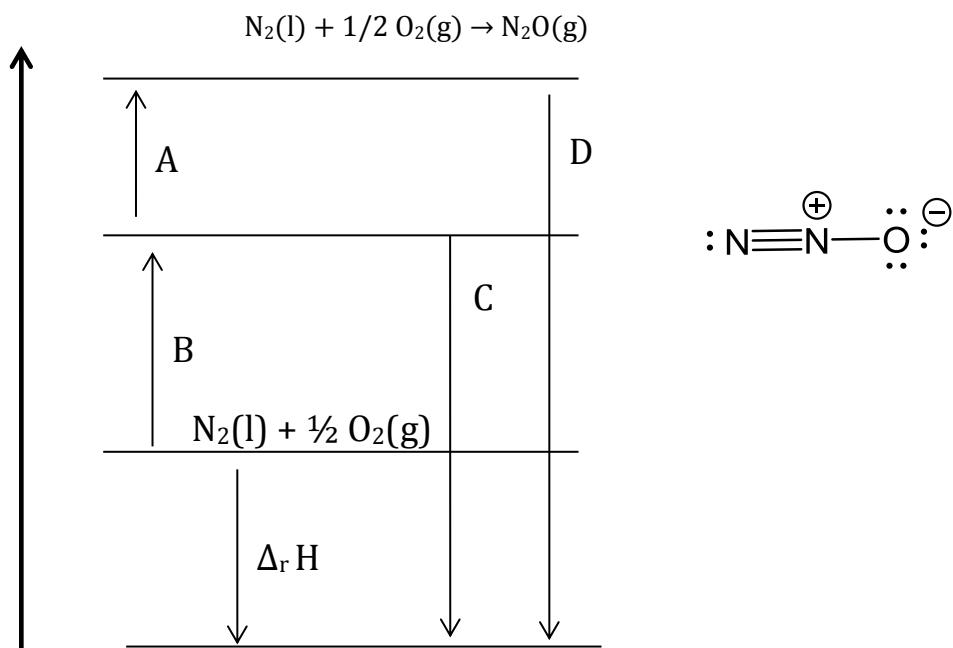
Hint: look at the states of the reaction $\Delta_{\text{vap}}H(\text{H}_2\text{O}) = 41\text{kJ/mol}$.



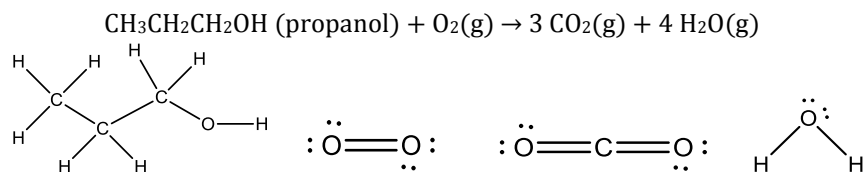
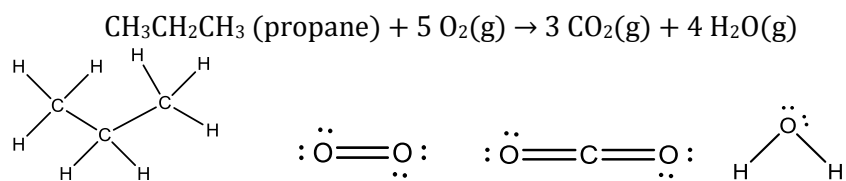
Use this information to determine the $\Delta_{\text{rxn}}H$ for the following reactions:



21. Fill in the horizontal lines using only the following species and their corresponding coefficients: $\text{N}_2(\text{g})$, $\text{N}(\text{g})$, $\text{O}(\text{g})$, $\text{O}_2(\text{g})$, $\text{N}_2\text{O}(\text{g})$. For the labeled arrows on the diagram, write the expression for the enthalpy change in terms of bond enthalpies and enthalpies of formation.



22. Alcohols are proposed as fuel sources for the future, and currently there are even cars that run on ethanol. The balanced chemical equations for the complete combustion of a standard alkane fuel and an alcohol are:



The result of combustion of one mole of propane is the same as combustion of one mole of propanol: three moles of carbon dioxide and four moles of water. This means the difference in the energy content of the two fuels is due to the bond enthalpies of the reactants. Which one propane or propanol makes a better fuel? *Hint: Use bond enthalpies calculate the enthalpy difference, $\Delta H_{propanol} - \Delta H_{propane}$, using the Lewis Structures above.*

Bond	O-H	C-H	C-O	C-C	O=O	C=O
$\Delta_b H(\text{kJ/mol})$	460.	410.	350.	350.	500.	750.

Remember, bond enthalpies give only approximate results for gas phase reactions. The actual enthalpies of combustion for propane and propanol are respectively: -2226 kJ/mol and -2020 kJ/mol. Seeing as you have to carry these fuels around with you, circle which fuel is more efficient on a per kilogram basis

Numerical Answers:

- Sometimes positive
 - Yes
- $\text{C}(\text{graphite}) + \frac{1}{2} \text{O}_2(\text{g}) + 2\text{H}_2(\text{g}) + \text{N}_2(\text{g}) \rightarrow \text{H}_2\text{NCONH}_2(\text{s})$
 $\Delta_r H^\circ = \Delta_f H^\circ(\text{H}_2\text{NCONH}_2(\text{s}))$
- $\text{C}_3\text{H}_8(\text{l}) + 5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g});$
 $100\% = -6116 \text{ kJ}$
 - $75\% = -4587 \text{ kJ}$
- $\Delta H_{\text{rxn}} = \Delta H_1 - 3/2 \Delta H_2 + 2 \Delta H_3 - \frac{1}{2} \Delta H_4$
- Always positive
50. kJ/mol
 - 93 kJ/mol
- $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\text{g})$
 - top: $4\text{H}(\text{g}) + 2 \text{O}(\text{g})$
middle: $2\text{H}_2\text{O}(\text{g})$
bottom: $2\text{H}_2\text{O}(\text{l})$
 - A: $2\Delta_b H(\text{H-H}) + \Delta_b H(\text{O=O})$
B: $-4\Delta_b H(\text{O-H})$
C: $-4\Delta_b H(\text{O-H}) - \Delta_{\text{vap}} H$
D: $2\Delta_f H(\text{H}_2\text{O}(\text{l}))$
 - -420.0 kJ/mol
- -42 kJ/mol
- $-40. \text{ kJ/mol}$
 - -120 kJ/mol
 - $-60. \text{ kJ}$
 - $40. \text{ kJ/mol}; 60. \text{ kJ}$
- 4 kJ/mol
- A: $\Delta_b H(\text{Na-Na}) + \Delta_b H(\text{Br-Br})$
B: $2^*(-\Delta_b H(\text{Na-Br}))$
C: $-\Delta_f H(\text{Na}_2(\text{g})) - \Delta_f H(\text{Br}_2(\text{g}))$
- Line 1: [Separated atoms]
 $2\text{N}(\text{g}) + 6\text{H}(\text{g})$
Line 2: [Reactants (standard states)]
 $\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g})$
Line 3: [Product] $2\text{NH}_3(\text{g})$
Line 4: [Product] $2\text{NH}_3(\text{l})$
A: $\Delta_b H(\text{N}\equiv\text{N}) + 3\cdot\Delta_b H(\text{H-H})$
B: $\Delta_{\text{rxn}} H$ or $2\cdot\Delta_f H(\text{NH}_3(\text{g}))$
C: $2\cdot\Delta_f H(\text{NH}_3(\text{l}))$
D: $2\Delta_{\text{vap}} H$
- $-360. \text{ kJ/mol}$
- $-92 \text{ kJ/mol}; -0.92 \text{ kJ}$
- $\Delta H_{\text{rxn}} = -1470 \text{ kJ/mol};$
 - $q_v = -4650 \text{ J}$
- $-900. \text{ kJ/mol}$
- $3/2 \Delta H_1 - \frac{1}{2} \Delta H_2 - 1/2 \Delta H_3 = \Delta H_f$
- -4.5 kJ
- $200. \text{ kJ/mol}$
 - $-450. \text{ kJ/mol}$
 - -75.0 kJ/mol
- -160 kJ/mol
 - -490 kJ/mol
 - -220 kJ
- $2 \text{N}(\text{g}) + \text{O}(\text{g})$
A: $\Delta H_B(\text{N}\equiv\text{N}) + \frac{1}{2} \Delta H_B(\text{O=O})$
 - $\text{N}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g})$
B: $-\Delta H_f(\text{N}_2(\text{l}))$
 - $\text{N}_2(\text{l}) + \frac{1}{2} \text{O}_2(\text{g})$
C: $\Delta H_f(\text{N}_2\text{O}(\text{g}))$
 - $\text{N}_2\text{O}(\text{g})$
D: $-\Delta H_B(\text{N}\equiv\text{N}) - \Delta H_B(\text{N-O})$
- Propane is better both by bond enthalpy and by enthalpies of combustion