

Thermochemistry Review Booklet

Topics Covered:

- a. Calorimetry
- b. Calculating ΔH using Hess's Law
- c. Communicating Enthalpy Change
- d. Activation Energy and Catalysts
- e. Other

Calorimetry Question

A student designed a calorimetry experiment to determine the mass of water that could be heated by 400 kJ of energy released by burning butane gas, and recorded the following results:

| | | | |
|------------|------------------------------|---------|------------|
| Δt | Initial temperature of water | 21.6 °C | |
| | Final temperature of water | 55.6 °C | |
| Q | Energy released | 400 kJ | ΔH |

The mass of water involved in this calorimetry experiment is 2.81 kg.

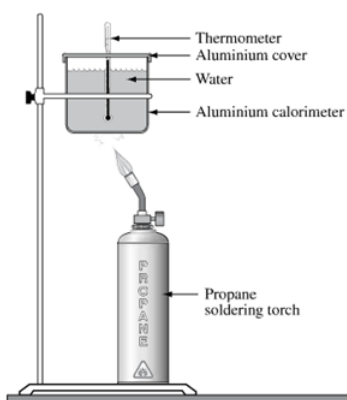
$$Q = mc\Delta t$$

$$400 \text{ kJ} = m (4.19 \text{ J/g}\cdot^\circ\text{C}) (34.0^\circ\text{C})$$

$$m = \frac{400 \text{ kJ}}{(4.19 \text{ J/g}\cdot^\circ\text{C}) (34.0^\circ\text{C})}$$

$$= 2.807 \dots \text{ kg}$$

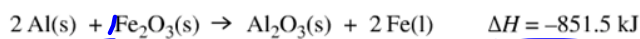
A technician performed an experiment to determine the molar enthalpy of combustion of propane in a soldering torch, as represented by the diagram below.



If the experimental value of the molar enthalpy of combustion of propane in the technician's calorimetry experiment is significantly different from the theoretical value, then the technician could reduce the discrepancy in the data by

- A. using a glass beaker to hold the water
- ☒ B. creating an enclosing shield around the apparatus
- C. raising the aluminium calorimeter higher above the flame
- D. decreasing the mass of water in the aluminium calorimeter

A thermite reaction is a highly exothermic process that is used in welding massive steel objects such as ship propellers and train rails. The reaction can be represented by the following equation.



If the heat produced by the reaction of 1.00 mol of iron(III) oxide were absorbed by 7.40 kg of $\text{H}_2\text{O(l)}$ at room temperature, then the resulting temperature change of the water would be 27.5 °C.

$$\Delta H = Q$$

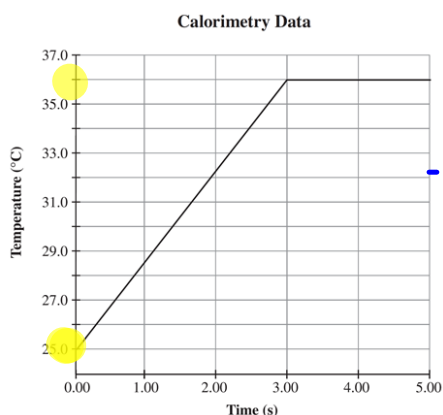
$$n \Delta_r H_m : mc\Delta t$$

$$(1.00 \text{ mol}) \left(\frac{851.5 \text{ kJ}}{\text{mol}} \right) = (7.40 \text{ kg}) (4.19 \text{ J/g}\cdot^\circ\text{C}) (\Delta t)$$

$$\Delta t = 27.46 \dots ^\circ\text{C}$$

Use the following information to answer the next two questions.

A student mixed 50.0 mL of 1.00 mol/L HCl(aq) with 50.0 mL of 1.00 mol/L NaOH(aq) in a calorimeter. The final mass of the resulting solution was 100.0 g, and the change in temperature of the resulting solution was recorded over time, as shown in the graph below.



The student assumed that the specific heat capacity of the final solution was the same as that of water and that the calorimeter neither gained nor lost heat.

Numerical Response

2. The energy transferred to the resulting solution in the student's experiment was 4.61 kJ.

(Record your three-digit answer in the numerical-response section on the answer sheet.)

$$Q = mc\Delta t$$

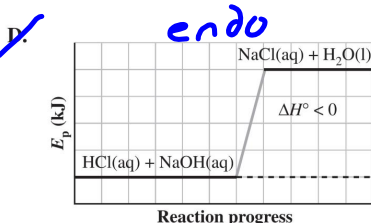
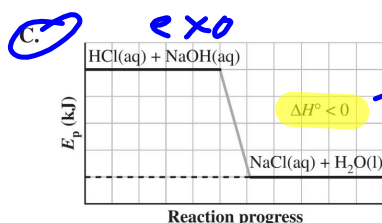
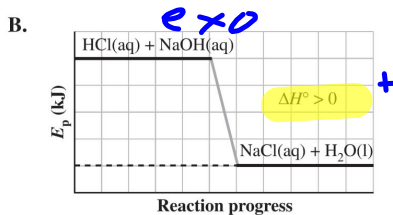
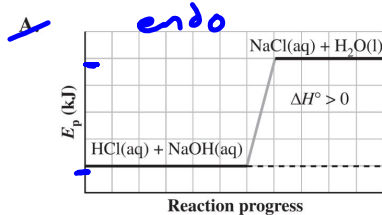
$$Q = (100.0\text{g})(4.19\frac{\text{J}}{\text{g}\cdot\text{C}})(11.0\text{C})$$

$$= 4609\text{J}$$

$$= 4.609\text{kJ}$$

$$= 4.61\text{kJ}$$

5. Which of the following potential energy diagrams represents the reaction that occurs during the student's experiment?



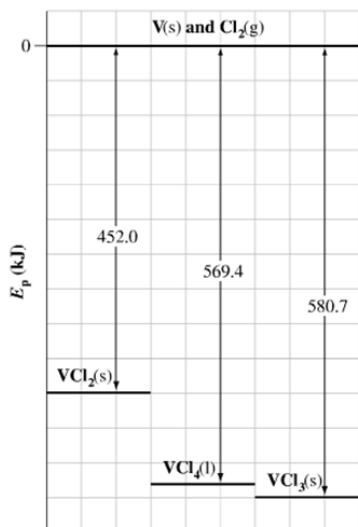
exothermic
ΔH = - value

endothermic
ΔH = + value

Calculating ΔH using Hess's Law

The following diagram illustrates the formation enthalpies of V(s), $\text{Cl}_2(\text{g})$, and a selection of their compounds.

Formation Enthalpies of Vanadium Chlorides



The amount of energy absorbed when 0.350 mol of $\text{VCl}_4(\text{l})$ decomposes to form $\text{VCl}_2(\text{s})$ and $\text{Cl}_2(\text{g})$ is _____ kJ.

Use the following information to answer the next 2 questions

- | | | |
|---|---|--------------------------------|
| 1 | $2 \text{ HF}_{(\text{g})} \rightarrow \text{H}_{2(\text{g})} + \text{F}_{2(\text{g})}$ | $\Delta H = +546.6 \text{ kJ}$ |
| 2 | $\text{C}_{(\text{s})} + 2 \text{ F}_{2(\text{g})} \rightarrow \text{CF}_{4(\text{g})}$ | $\Delta H = -933.6 \text{ kJ}$ |
| 3 | $2 \text{ C}_{(\text{s})} + 2 \text{ H}_{2(\text{g})} \rightarrow \text{C}_2\text{H}_{4(\text{g})}$ | $\Delta H = -52.4 \text{ kJ}$ |

1. When using the reactions above to calculate the enthalpy change for the following reaction, $\text{C}_2\text{H}_{4(\text{g})} + 2 \text{ F}_{2(\text{g})} \rightarrow 2 \text{ CF}_{4(\text{g})} + 4 \text{ HF}_{(\text{g})}$, then

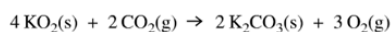
the equations that must be doubled are numbered _____ and _____, and the equations that must be reversed are numbered _____ and _____.

2. The energy released by the following reaction is _____ kJ.
 $\text{C}_2\text{H}_{4(\text{g})} + 2 \text{ F}_{2(\text{g})} \rightarrow 2 \text{ CF}_{4(\text{g})} + 4 \text{ HF}_{(\text{g})}$ $\Delta H = ?$



The energy released when 1.50 g of methane gas, $\text{CH}_4(\text{g})$, is burned is _____ kJ.

Scuba divers who want to observe sharks will often use a rebreather, which is a self-contained breathing device. A rebreather allows divers to spend a longer time under water and prevents the release of exhaled bubbles that could scare away sharks. Potassium superoxide, $\text{KO}_2(\text{s})$, is used in some rebreathers to remove carbon dioxide from exhaled air. The equation for this reaction is shown below.



$$\Delta_f H^\circ_{\text{KO}_2} = -284.9 \text{ kJ/mol}$$

$$\Delta_f H^\circ_{\text{K}_2\text{CO}_3} = -1152.7 \text{ kJ/mol}$$

Which of the following rows identifies the type of reaction represented above and the type of ΔH value?

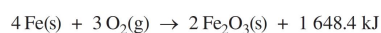
| Row | Type of Reaction | ΔH Value |
|-----|------------------|------------------|
| A. | Endothermic | Negative |
| B. | Endothermic | Positive |
| C. | Exothermic | Negative |
| D. | Exothermic | Positive |

The molar enthalpy of combustion of propane is

- A. -103.8 kJ/mol
- B. -2043.9 kJ/mol
- C. -2219.9 kJ/mol
- D. -2251.5 kJ/mol

Use the following information to answer the next question.

A hand-warmer packet contains a mixture of powdered iron, carbon, sodium chloride, sawdust, and zeolite, all moistened by a little water. The packet is activated by removing the plastic cover, which exposes the materials in the packet to air. The reaction that occurs is represented by the following equation.



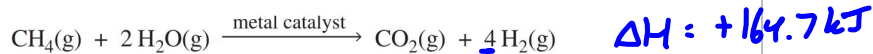
Numerical Response

3. When 2.50 g of $\text{Fe}_2\text{O}_3(\text{s})$ is produced in the hand-warmer packet, the energy transferred is _____ kJ.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Use the following information to answer the next question.

Aerospace engineers are interested in using hydrogen gas as fuel in airplanes because of its low density. Hydrogen gas can be produced by the reaction represented by the following overall equation.



2. The enthalpy change for the reaction represented by the equation above is i, and the enthalpy change per mole of hydrogen is ii.

The statement above is completed by the information in row

| Row | i | ii |
|-----------|-----------|---------------|
| A. | +164.7 kJ | +658.8 kJ/mol |
| B. | +164.7 kJ | +41.2 kJ/mol |
| C. | -77.1 kJ | -308.4 kJ/mol |
| D. | -77.1 kJ | -19.3 kJ/mol |

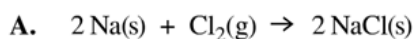
$\Delta H/4$

$$\Delta_r H = \left[(1 \text{ mol}) (-393.5 \text{ kJ/mol}) - \left[(1 \text{ mol} \times -74.6 \text{ kJ/mol}) + (2 \text{ mol} \times -241.8 \text{ kJ/mol}) \right] \right]$$

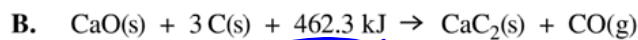
$$\Delta_r H = +164.7 \text{ kJ}$$

Communicating Enthalpy Change

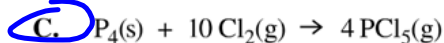
Which of the following reactions would release the **largest** amount of energy?



$\Delta_r H = -822.4 \text{ kJ}$



$\Delta_r H = +462.3 \text{ kJ}$



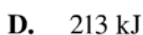
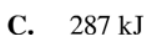
$\Delta H^\circ = -1772 \text{ kJ}$



$\Delta_r H = -1322.9 \text{ kJ}$

ΔH

The energy required to completely decompose 1.50 mol of $\text{PCl}_3(\text{l})$ is



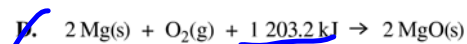
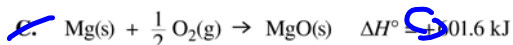
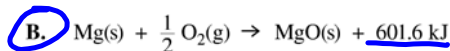
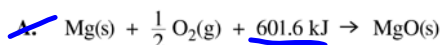
$\Delta_f H_m = -389.7 \text{ kJ/mol}$
PCl₃

$\Delta_d H_m = +389.7 \text{ kJ/mol}$
 $n = 1.50 \text{ mol}$

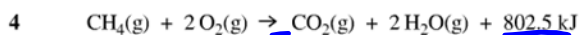
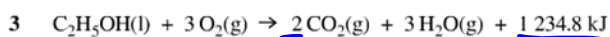
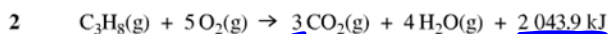
$\Delta_r H = n \Delta_r H_m$
 $= 480 \text{ kJ}$

A fire fuelled by burning magnesium metal produces a brilliant white light and intense heat, which makes fighting the fire very difficult. Firefighters extinguish this type of fire by smothering it with sand.

Which of the following equations represents the burning of magnesium?



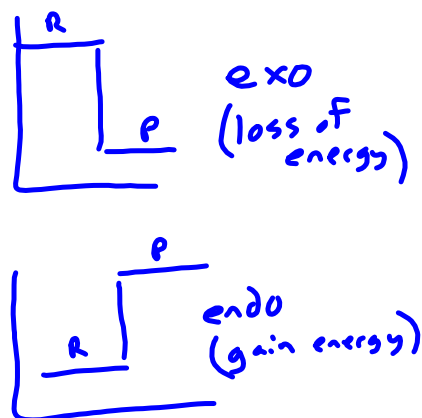
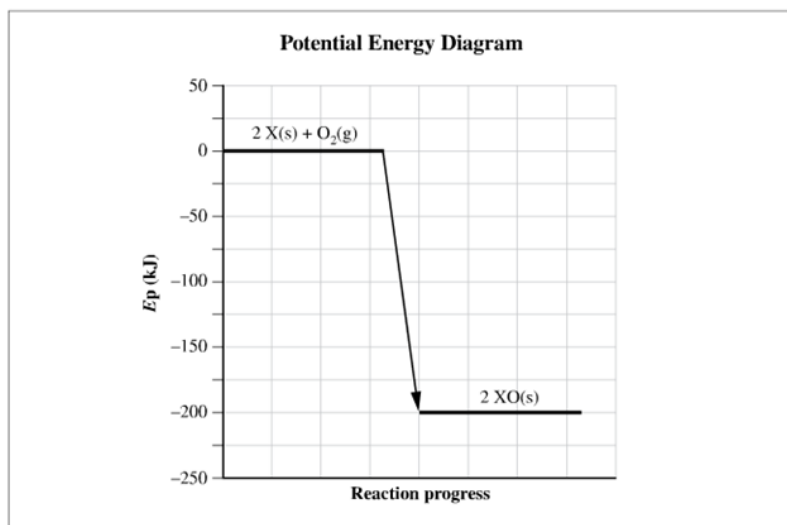
Equations



When ranked in order from the reaction that has the **smallest** enthalpy change per mole of carbon dioxide gas to the reaction that has the **largest** enthalpy change per mole of carbon dioxide gas, the reactions are

3, 1, 2, and 4
Smallest Largest

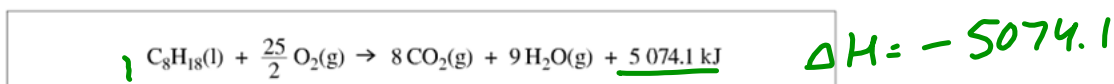
$\frac{5074.1}{8} = 634.3$
 $\frac{2043.9}{3} = 681.3$
 $\frac{1234.8}{2} = 621.9$
 $\frac{802.5}{1} = 802.5$



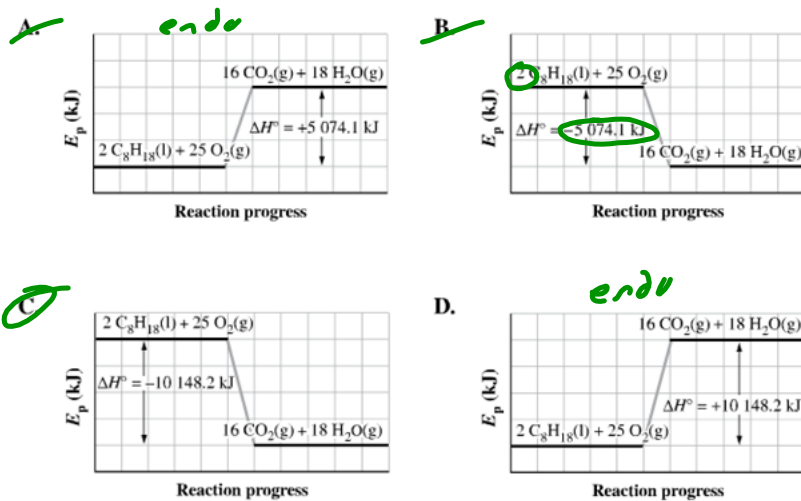
The reaction represented by the graph above is i and the energy term would be included as a ii in the balanced chemical equation.

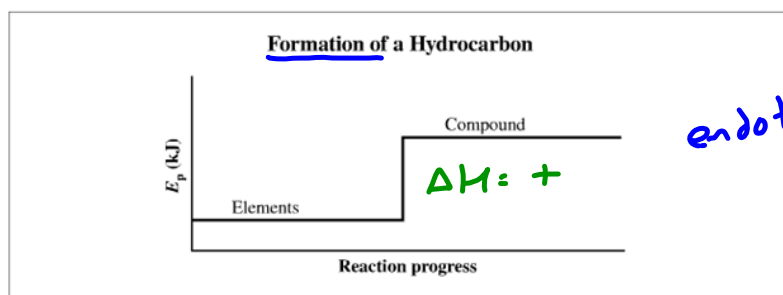
The statement above is completed by the information in row

| Row | i | ii |
|-----------|-------------|----------|
| A. | exothermic | product |
| B. | exothermic | reactant |
| C. | endothermic | product |
| D. | endothermic | reactant |



Which of the following potential energy diagrams represents the equation above?





endothermic

The graph above could represent the formation of

- ☒ A. ethene
- ☐ B. ethane
- ☐ C. butane
- ☐ D. pentane

Hydrogen cyanide, HCN(g), a poisonous and volatile gas, is used in the manufacture of dyes and explosives. It is produced by the reaction represented by the following equation.



$$\Delta H = +255.6 \text{ kJ}$$

27. The molar enthalpy of formation of gaseous hydrogen cyanide is

- ☐ A. +376.1 kJ/mol
- ☒ B. +135.1 kJ/mol
- ☐ C. -135.1 kJ/mol
- ☐ D. -376.1 kJ/mol

$$+255.6 \text{ kJ} = \left[(1 \text{ mol}) (\Delta_f H_m) \right] - \left[(1 \text{ mol} \times -74.6 \frac{\text{kJ}}{\text{mol}}) + (1 \text{ mol} \times -45.9 \frac{\text{kJ}}{\text{mol}}) \right]$$

$$\Delta_f H_m : +135.1 \text{ kJ/mol}$$

HCN

Use the following information to answer the next question.

| Chemical Equations | | |
|--------------------|--|-----------------------------------|
| 1 | $\text{C(s)} + 2\text{H}_2\text{O(g)} + 90.1\text{ kJ} \rightarrow \underline{1}\text{CO}_2\text{(g)} + 2\text{H}_2\text{(g)}$ | $+90.1$ |
| 2 | $\text{CO(g)} + \text{H}_2\text{O(g)} \rightarrow \underline{1}\text{CO}_2\text{(g)} + \text{H}_2\text{(g)} + 41.2\text{ kJ}$ | -41.2 |
| 3 | $\text{C}_2\text{H}_5\text{OH(l)} + 3\text{O}_2\text{(g)} \rightarrow \underline{2}\text{CO}_2\text{(g)} + 3\text{H}_2\text{O(g)}$ | $\Delta H = -514.1\text{ kJ} / 2$ |
| 4 | $\text{C}_3\text{H}_8\text{(g)} + 6\text{H}_2\text{O(g)} \rightarrow \underline{3}\text{CO}_2\text{(g)} + 10\text{H}_2\text{(g)}$ | $\Delta H = +374.1\text{ kJ} / 3$ |

$+90.1$
 -41.2
 -257.05
 $+124.7$

Numerical Response

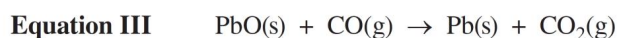
1. When the equations numbered above are ordered from the reaction that **absorbs** the most energy per mole of carbon dioxide gas to the reaction that **releases** the most energy per mole of carbon dioxide gas, the order is

4, 1, 2, and 3.
 Most absorbed, and Most released

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Use the following information to answer the next question.

Much of the lead used for batteries and ammunition during the First World War and the Second World War came from galena, PbS(s) . The following equations represent the reactions that are involved in refining galena to produce solid lead.

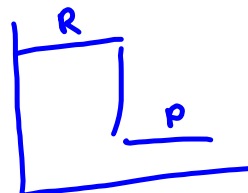


product side

3. In Equation I, the reactants have i energy than the products, and if energy were included as a term in the equation, it would be a ii.

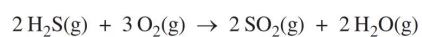
The statement above is completed by the information in row

| Row | i | ii |
|-----------|------|----------|
| A. | less | reactant |
| B. | less | product |
| C. | more | reactant |
| <u>D.</u> | more | product |



Use the following information to answer the next question.

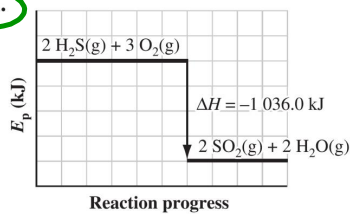
Hydrogen sulfide gas undergoes a combustion reaction with oxygen to produce gaseous sulfur dioxide and water vapour.



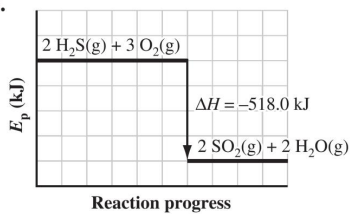
$$\Delta_r H: -1036$$

4. The potential energy diagram, including the enthalpy change, associated with the combustion of hydrogen sulfide gas is

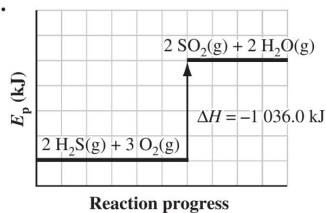
A.



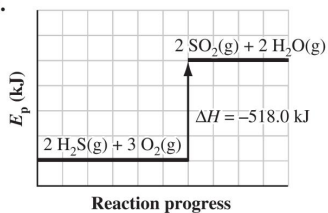
B.



C.



D.



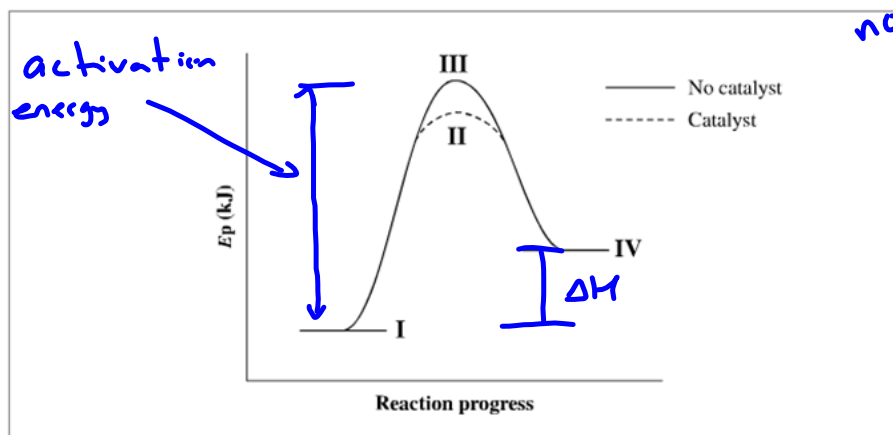
Activation Energy and Catalysts



In the beer-making process, starch in the grain must be converted to sugar before fermentation can occur. The starch can be converted to sugar either by heating it or by adding a biological catalyst that

- A. ~~increases~~ the amount of energy required for the process
- B. allows the process to occur at ~~higher~~ temperatures
- C. ~~increases~~ the time it takes to convert the starch to sugar
- D.** decreases the time it takes to convert the starch to sugar

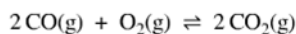
Catalysts
 \downarrow E needed
 \downarrow Temp
 \downarrow time
 no effect on ΔH



The activation energy for the forward, catalyzed reaction is

- A.** II minus I
- B. III minus I
- C. IV minus II
- D. IV minus III

Incomplete combustion in motor vehicles may lead to the formation of carbon monoxide gas, which is a health hazard in high concentrations. Carbon monoxide gas is converted to carbon dioxide gas in a catalytic converter before being emitted from the motor vehicle. This conversion is represented by the equation below.



The addition of a catalyst to the reaction represented by the equation above would i the energy transferred during the reaction and would ii the rate of the forward reaction.

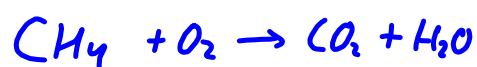
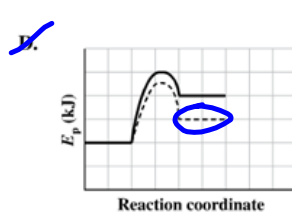
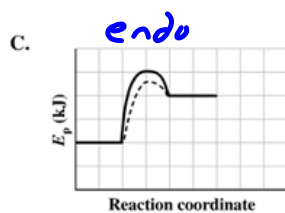
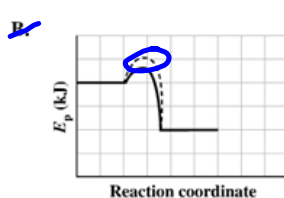
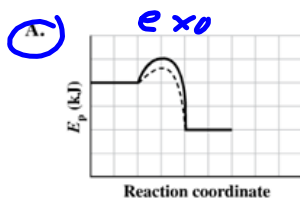
The statement above is completed by the information in row

| Row | i | ii |
|-----------|-----------------|------------|
| A. | <u>increase</u> | increase |
| B. | <u>increase</u> | not change |
| C. | not change | increase |
| D. | not change | not change |

Catalysts
 don't change ΔH or equilibrium

Dr. Richard Trotter has developed what could be the first cost-effective process for limiting methane emissions from underground coal mines. In this process, methane and oxygen are reacted at 800 °C in the presence of a catalyst. The products of this process are carbon dioxide gas and liquid water.

Which of the following potential energy diagrams represents both the catalyzed (----) and uncatalyzed (—) reactions for this process?



hydrocarbon combustion
- always exothermic

Other

| Chemicals | | | | | |
|-----------|---------------------|---|--|--|--|
| 1 | O ₂ (g) | 4 | H ₂ O(l) | | |
| 2 | CO(g) | 5 | H ₂ O(g) | | |
| 3 | CO ₂ (g) | 6 | C ₆ H ₁₂ O ₆ (aq) | | |

Match the chemicals numbered above with the statements given below.

The reactants in photosynthesis are:

3 and 4
Record as the first digit Record as the second digit

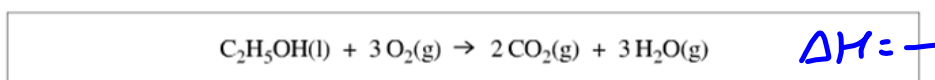
The products of complete hydrocarbon combustion in an open system are:

3 and 5
Record as the third digit Record as the fourth digit

| Equations | |
|-----------|--|
| 1 | $\text{C}_8\text{H}_{18}(\text{l}) + \frac{25}{2} \text{O}_2(\text{g}) \rightarrow 8 \text{CO}_2(\text{g}) + 9 \text{H}_2\text{O}(\text{g}) + 5\,074.1 \text{ kJ}$ |
| 2 | $\text{C}_3\text{H}_8(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{g}) + 2\,043.9 \text{ kJ}$ |
| 3 | $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{g}) + 1\,234.8 \text{ kJ}$ |
| 4 | $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g}) + 802.5 \text{ kJ}$ |

The original source of energy for the reactants in the four reactions represented by the equations above is

- A. the Sun
- B. a fossil fuel
- C. a combustion reaction
- D. a decomposition reaction



During the reaction represented above, energy is i the surroundings because the reaction is ii.

The statement above is completed by the information in row

| Row | i | ii |
|-----------|--------------------------|------------------------|
| <u>A.</u> | released to | exothermic |
| B. | released to | endothermic |
| C. | absorbed from | exothermic |
| D. | <u>absorbed from</u> | endothermic |

When methane gas is burned in a fireplace, the reaction that occurs is *i* . The original source of the energy stored in the methane gas is *ii* .

The statements above are completed by the information in row

| Row | <i>i</i> | <i>ii</i> |
|-----------|------------------------|------------------------|
| A. | endothermic | fossil fuel |
| B. | endothermic | the Sun |
| C. | exothermic | fossil fuel |
| <u>D.</u> | exothermic | the Sun |