

## Thermodynamics Worksheet

Fill the blanks in the following sentences with the correct thermodynamics term:

- 1) The thing we measure when we want to determine the average kinetic energy of random motion in the particles of a substance is **temperature**.
- 2) The **specific heat** is the energy needed to raise the temperature of one gram of a substance one degree Celsius.
- 3) A(n) **exothermic** reaction is one where the products have lower energy than the reactants.
- 4) **Endothermic** reactions require energy in order to take place.
- 5) **Spontaneous** changes take place by themselves, without any help.
- 6) The **enthalpy change ( $\Delta H$ )** is used to describe how much energy is produced or used during a chemical change.
- 7) **Potential energy** is energy that is stored chemical energy.
- 8) **Kinetic energy** is energy associated with the movement of an object.
- 9) **Heat** is a form of energy transfer to or from a system. which occurs from hot to cold.
- 10) Sign Convention: Heat gained (absorbed) is considered **+**; heat lost by system to surroundings is **-**.
- 11) A **calorimeter** is a device used to measure heat transfer.
- 12) The **standard enthalpy of formation** is the enthalpy change in the formation of one mole of a compound when formed in the standard state ( $T = 298 \text{ K}$ ;  $P = 1 \text{ atm}$ ) from its elements.
- 13) **Hess's Law** states that enthalpies of individual reactions can be added to calculate enthalpy of overall reaction.
- 14) The **joule** is a metric unit of energy equal to  $1 \text{ kg}\cdot\text{m}^2/\text{sec}^2$ .

## Thermodynamics Worksheet

Fill the blanks in the following sentences with the correct thermodynamics term:

- 1) The thing we measure when we want to determine the average kinetic energy of random motion in the particles of a substance is \_\_\_\_\_.
- 2) The \_\_\_\_\_ is the energy needed to raise the temperature of one gram of a substance one degree Celsius.
- 3) A(n) \_\_\_\_\_ reaction is one where the products have lower energy than the reactants.
- 4) \_\_\_\_\_ reactions require energy in order to take place.
- 5) \_\_\_\_\_ changes take place by themselves, without any help.
- 6) The \_\_\_\_\_ is used to describe how much energy is produced or used during a chemical change.
- 7) \_\_\_\_\_ is energy that is stored chemical energy.
- 8) \_\_\_\_\_ is energy associated with the movement of an object.
- 9) \_\_\_\_\_ is a form of energy transfer to or from a system. which occurs from hot to cold.
- 10) Sign Convention: Heat gained (absorbed) is considered \_\_\_\_\_; heat lost by system to surroundings is \_\_\_\_\_.
- 11) A \_\_\_\_\_ is a device used to measure heat transfer.
- 12) The \_\_\_\_\_ is the enthalpy change in the formation of one mole of a compound when formed in the standard state ( $T = 298 \text{ K}$ ;  $P = 1 \text{ atm}$ ) from its elements.
- 13) \_\_\_\_\_ states that enthalpies of individual reactions can be added to calculate enthalpy of overall reaction.
- 14) The \_\_\_\_\_ is a metric unit of energy equal to  $1 \text{ kg m}^2/\text{sec}^2$ .

Practice Problems:

- 1) A 12 oz. can of soda weighs about 450. grams. How many joules are released when a can of soda is cooled from 25.0 degrees Celsius (room temperature) to 4.0 degrees Celsius (the temperature of a refrigerator). The heat capacity of liquid water is  $4.18 \text{ J/g} \cdot ^\circ\text{C}$ .

$$q = m \cdot c \cdot \Delta T$$
$$q = (450. \text{g})(4.18 \text{ J/g} \cdot ^\circ\text{C})(25.0 - 4.0)$$
$$q = -39,510 \text{ J} \quad (-39.5 \text{ kJ})$$

- 2) How many joules are required to heat 250. grams of liquid water from 0.0°C to 100.0°C?

$$q = m \cdot c \cdot \Delta T$$

$$q = (250. \text{g})(4.184 \text{ J/g} \cdot ^\circ\text{C})(100.0^\circ\text{C})$$

$$q = +105,000 \text{ J}$$

- 3) By how many degrees Celsius would the temperature of 3 kg of a substance change if the substance absorbed 4.328 kJ of energy? Assume that the specific heat of the substance equals 0.630 J/g°C. (105. kJ)

$$q = m \cdot c \cdot \Delta T$$

$$\Delta T = \frac{q}{m \cdot c}$$

$$\Delta T = \frac{4328 \text{ kJ}}{3000 \text{ g} \cdot 0.630 \text{ J/g} \cdot ^\circ\text{C}} = 2^\circ\text{C}$$

- 4) What amount of heat is released when the temperature of 450.0 g of a substance drops by 7.050°C? Assume that the specific heat equals 1.264 J/g°C. (2°C)

$$q = m \cdot c \cdot \Delta T$$

$$q = (450.0 \text{ g})(1.264 \text{ J/g} \cdot ^\circ\text{C})(7.050^\circ\text{C})$$

$$q = -4010 \text{ J}$$

- 5) If 2.508 kg of a substance increases in temperature by 4.051°C when it absorbs 3.42 kJ of energy, what is the specific heat of the substance, in J/g°C? (-4010 J)

$$q = m \cdot c \cdot \Delta T$$

$$c = \frac{q}{m \cdot \Delta T}$$

$$c = \frac{3420 \text{ J}}{2508 \text{ g} \cdot 4.051^\circ\text{C}} = .337 \text{ J/g} \cdot ^\circ\text{C}$$

(0.337 J/g°C)

- 6) A calorimeter that contains 2.5 kg of water is used to measure the heat associated with the reaction of 520 g of a reactant added to the water. Calculate the energy, in joules per gram of reactant, associated with the reaction if the temperature of the water changes from 27.40°C to 20.28°C. Assume that the specific heat of water is 4.184 J/g°C. Is the reaction exothermic or endothermic?

$$m = 2500 \text{ g} + 520 \text{ g} = 3020 \text{ g}$$

$$q = 3020 \text{ g} \cdot 4.184 \text{ J/g} \cdot \text{C} \cdot (27.40^\circ\text{C} - 20.28^\circ\text{C})$$

$$q = \frac{89966 \text{ J}}{520 \text{ g reactant}} = 170 \text{ J/g}$$

(170 J/g; endothermic)

- 7) A calorimeter that contains 6.050 kg of surrounding water is used to measure the heat associated with the dissolving of 0.50 mole of NaOH. If the initial temperature of the water is 15.0°C and the final temperature is 19.5°C, how much heat, in joules per mole of reactant, is associated with the reaction? Assume the specific heat of the solution is the same as that of water. Is the reaction exothermic or endothermic?

$$q = 6050 \text{ g} \cdot 4.184 \text{ J/g} \cdot \text{C} \cdot 4.5^\circ\text{C} = 113909 \text{ J}$$

$$\frac{0.50 \text{ mol NaOH}}{113909 \text{ J}} = \frac{1 \text{ mol}}{x \text{ J}} \quad x = 227818 \rightarrow 2.3 \times 10^5 \text{ J/mol}$$

( $2.3 \times 10^5$  J/mol; exothermic)

- 8) If you burn 0.315 moles of hexane ( $\text{C}_6\text{H}_{14}$ ) in a bomb calorimeter (the combustion material is separated from the water so its mass should not be included in your energy calculation) containing 5.65 liters of water, what's the molar heat of combustion of hexane if the water temperature rises 55.4°C? The heat capacity of water is 4.184 J/g°C.

$$q = 5650 \text{ g} \cdot 4.184 \text{ J/g} \cdot \text{C} \cdot 55.4^\circ\text{C} = 1309634 \text{ J}$$

$$\frac{0.315 \text{ mol}}{1309634 \text{ J}} = \frac{1 \text{ mol}}{x \text{ J}} \quad x = 4157.567 \text{ kJ}$$

$$4160 \text{ or } 4.16 \times 10^3 \text{ kJ/mol}$$

(4160 kJ/mol)

- 9) If you burn 22.0 grams of propane ( $\text{C}_3\text{H}_8$ ) in a bomb calorimeter containing 3.25 liters of water, what's the molar heat of combustion of propane if the water temperature rises 29.5°C?

$$q = 3250 \text{ g} \cdot 4.184 \text{ J/g} \cdot \text{C} \cdot 29.5^\circ\text{C}$$

$$m m \text{ C}_3\text{H}_8 = 44.1 \text{ g/mol}$$

$$q = 401141 \text{ J}$$

$$\frac{22.0 \text{ g}}{44.1 \text{ g/mol}} = 0.4988 \text{ mol}$$

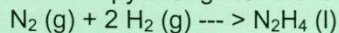
$$\frac{0.4988 \text{ mol}}{401141 \text{ J}} = \frac{1 \text{ mol}}{x \text{ J}} \quad x = 804 \text{ kJ/mol}$$

(804 kJ/mol)

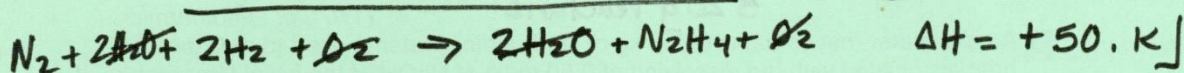
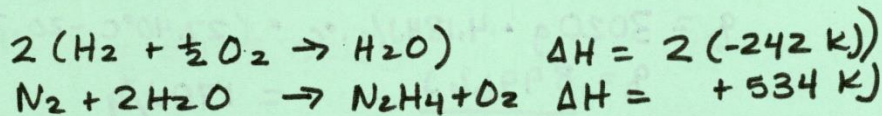
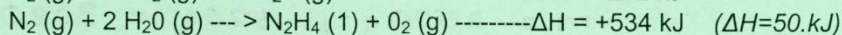
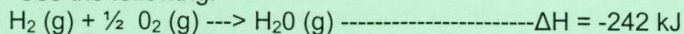
- 10) As it turns out, the data from the two experiments described above would not give the correct molar heats of combustion for the compounds stated. Explain why this is, based on your knowledge of how calorimetry works.

Heat is lost to calorimeter and air!

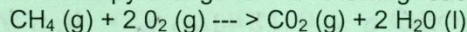
11) What is the enthalpy change for the following reaction?



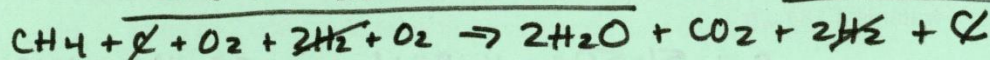
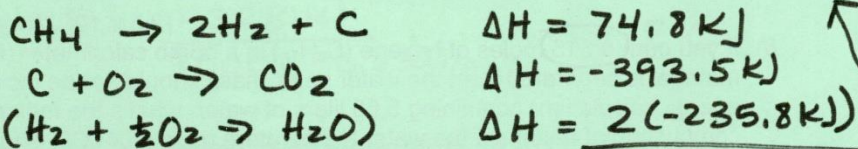
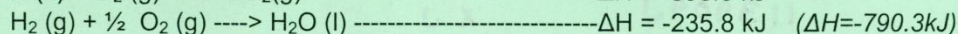
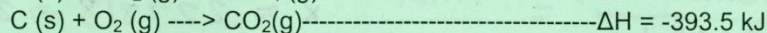
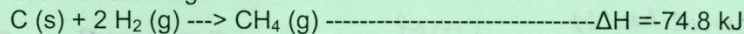
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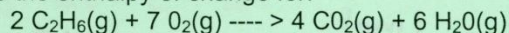
12) What is the enthalpy change for the following reaction?



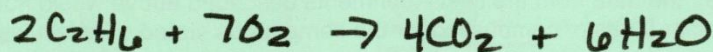
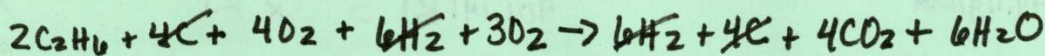
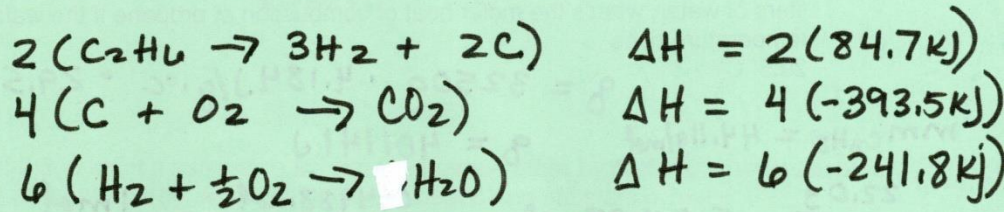
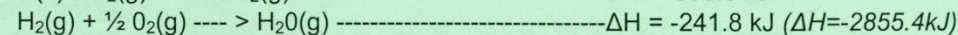
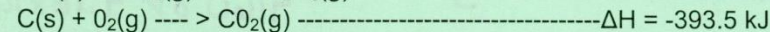
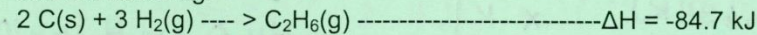
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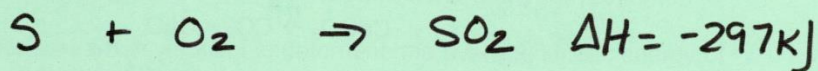
13) Calculate the enthalpy of change for:



Use the following:



- 14) The standard heat of formation,  $\Delta H$  of, for sulfur dioxide ( $\text{SO}_2$ ) is  $-297 \text{ kJ/mol}$ . How many kJ of energy are given off when  $25.0 \text{ g}$  of  $\text{SO}_2$  ( $\text{g}$ ) is produced from its elements?

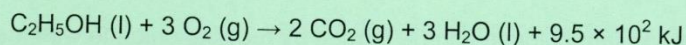


$$\frac{25.0 \text{ g SO}_2}{64.07 \text{ g/mol}} = 0.3902 \text{ mol SO}_2$$

$$\frac{1 \text{ mol SO}_2}{-297 \text{ kJ}} = \frac{0.3902 \text{ mol SO}_2}{x \text{ kJ}} \quad x = -116 \text{ kJ}$$

(-116 kJ)

- 15) The heat of reaction for the combustion of 1 mol of ethyl alcohol is  $-9.50 \times 10^2 \text{ kJ}$ :



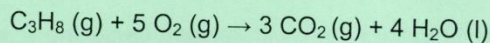
How much heat is produced when  $11.5 \text{ g}$  of alcohol is burned?

$$\frac{11.5 \text{ g C}_2\text{H}_5\text{OH}}{46.08 \text{ g/mol}} = 0.2496 \text{ mol C}_2\text{H}_5\text{OH}$$

$$\frac{1 \text{ mol C}_2\text{H}_5\text{OH}}{9.5 \times 10^2 \text{ kJ}} = \frac{0.2496 \text{ mol}}{x \text{ kJ}}$$

$$x = 238 \text{ kJ} \quad (2.38 \times 10^2 \text{ kJ})$$

- 16)  $\Delta H$  for the complete combustion of 1 mol of propane is  $-2.22 \times 10^3 \text{ kJ}$ :



Calculate the heat of reaction for the combustion of  $33.0 \text{ g}$  of propane.

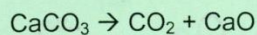
$$\frac{33.0 \text{ g C}_3\text{H}_8}{44.11 \text{ g/mol}} = 0.7481 \text{ mol C}_3\text{H}_8$$

$$\frac{1 \text{ mol}}{2.22 \times 10^3 \text{ kJ}} = \frac{0.7481 \text{ mol}}{x \text{ kJ}}$$

$$x = 1660 \text{ kJ}$$

( $1.67 \times 10^3 \text{ kJ}$ )

- 17) Calcium carbonate decomposes at high temperature to form carbon dioxide and calcium oxide:

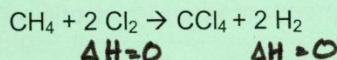


Given that the heat of formation of calcium carbonate is  $-1207 \text{ kJ/mol}$ , the heat of formation of carbon dioxide is  $-394 \text{ kJ/mol}$ , and the heat of formation of calcium oxide is  $-635 \text{ kJ/mol}$ , determine the heat of reaction.

$$\begin{aligned}\Delta H_{\text{rxn}} &= [1(-394\text{kJ}) + 1(-635\text{kJ})] - [1(-1207\text{kJ})] \\ &= +178 \text{ kJ}\end{aligned}$$

$(\Delta H_{\text{rxn}} = +178 \text{ kJ})$

- 18) Carbon tetrachloride can be formed by reacting chlorine with methane:

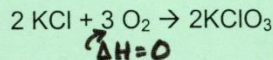


Given that the heat of formation of methane is  $-75 \text{ kJ/mol}$  and the heat of formation of carbon tetrachloride is  $-135 \text{ kJ/mol}$ , determine the heat of reaction.

$$\Delta H_{\text{rxn}} = (-135) - (-75) = -60, \text{kJ}$$

$(\Delta H_{\text{rxn}} = -60. \text{kJ})$

- 19) When potassium chloride reacts with oxygen under the right conditions, potassium chlorate is formed:



Given that the heat of formation of potassium chloride is  $-436 \text{ kJ/mol}$  and the heat of formation of potassium chlorate is  $-391 \text{ kJ/mol}$ , determine the heat of reaction.

$$\Delta H = [2(-391\text{kJ})] - [2(-436\text{kJ})] = 90\text{kJ}$$

$(\Delta H_{\text{rxn}} = 90. \text{kJ})$