

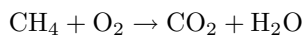
Balancing chemical reaction equations (stoichiometry)

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Questions

Question 1

When methane (CH_4) and oxygen (O_2) gas combine under sufficient pressure and/or temperature, they react to form carbon dioxide (CO_2) gas and water (H_2O). The following chemical equation shows the combustion of methane and oxygen to form carbon dioxide and water:



Unfortunately, this equation is incomplete. Although it does indicate the *identities* of the reaction products (carbon dioxide and water), it does not indicate their *relative quantities*. A simple head-count of atoms on each side of the equation confirms this:

Reactants	Reaction products
Carbon = 1	Carbon = 1
Hydrogen = 4	Hydrogen = 2
Oxygen = 2	Oxygen = 3

Since we know it would violate the Law of Mass Conservation (one of the fundamental laws of physics) to have fewer atoms of each element coming out of a reaction than going into it, we know this equation must be incomplete.

To make this a *balanced* equation, we must determine how many molecules of methane, oxygen, carbon dioxide, and water are involved in this reaction so that the numbers of atoms for each element are the same on both sides of the equation.

Re-write this chemical equation so that it is balanced.

Furthermore, calculate the number of moles of oxygen gas needed to completely react (burn) 1400 moles of methane gas under ideal conditions.

[file i00570](#)

Question 2

When the sugar *glucose* ($\text{C}_6\text{H}_{12}\text{O}_6$) ferments, the result is the production of carbon dioxide (CO_2) and ethanol ($\text{C}_2\text{H}_5\text{OH}$). This is the chemical reaction on which all alcohol beverage industries are founded: the conversion of sugar into ethanol. The following chemical equation shows the conversion of glucose into carbon dioxide and ethanol:



Unfortunately, this equation is incomplete. Although it does indicate the *identities* of the reaction products (carbon dioxide and ethanol), it does not indicate their *relative quantities*. Re-write this chemical equation so that it is balanced.

Suggestions for Socratic discussion

- Fermentation is a process strongly influenced by pH. Is this evident from the balanced equation, or not?
- Is fermentation an endothermic or exothermic process? How may we tell by this chemical equation?

[file i00572](#)

Question 3

Silane is a flammable and toxic gas (SiH_4 , also called silicon tetrahydride) used widely in silicon semiconductor manufacturing processes. If a leak develops in a pipe carrying silane, the result is immediate combustion, each molecule of silane gas combining with two molecules of atmospheric oxygen (O_2).

One of the products of silane + oxygen combustion is water vapor (2 molecules of H_2O produced for each molecule of silane). There is only one other combustion product. Determine what this product is, and how many molecules of it are produced for each molecule of silane gas entering the reaction.

[file i00575](#)

Question 4

When pentane (C_5H_{12}) is burned with oxygen (O_2) under ideal conditions, the products are water vapor (H_2O) and carbon dioxide (CO_2). Write a balanced equation showing all reactants and all reaction products in the proper proportions.

[file i00905](#)

Question 5

When propane (C_3H_8) is burned with oxygen (O_2) under ideal conditions, the products are water vapor (H_2O) and carbon dioxide (CO_2). Write a balanced equation showing all reactants and all reaction products in the proper proportions.

[file i00902](#)

Question 6

When butane (C_4H_{10}) is burned with oxygen (O_2) under ideal conditions, the products are water vapor (H_2O) and carbon dioxide (CO_2). Write a balanced equation showing all reactants and all reaction products in the proper proportions.

[file i00904](#)

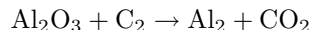
Question 7

When ethane (C_2H_6) is burned with oxygen (O_2) under ideal conditions, the products are water vapor (H_2O) and carbon dioxide (CO_2). Write a balanced equation showing all reactants and all reaction products in the proper proportions.

[file i00900](#)

Question 8

The *Hall* process for converting alumina (Al_2O_3) into metallic aluminum (Al) involves electrolysis with carbon electrodes. A powerful electric current forces carbon to join with the oxygen atoms in the alumina, forming carbon dioxide (CO_2) gas. The chemical equation describing this reaction is shown here:

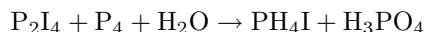


Balance this equation so that all molecules appear in their proper proportions. Also, determine how many pounds of carbon electrode must be consumed in this process to yield three tons (6000 pounds) of metallic aluminum, assuming perfect conversion efficiency.

[file i02353](#)

Question 9

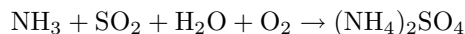
Balance the following chemical reaction:



[file i04304](#)

Question 10

Ammonium sulfate, having the chemical formula $(\text{NH}_4)_2\text{SO}_4$, may be produced from ammonia (NH_3), sulfur dioxide (SO_2), water (H_2O), and oxygen (O_2) by the following (unbalanced) chemical reaction:

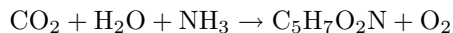


Balance this chemical reaction, showing all the reactants and reaction products in their proper proportions.

[file i00111](#)

Question 11

Microbes (bacteria) involved with the digestion of organic waste must form the material necessary to multiply their numbers from compounds available to them. Assuming a formulation of $\text{C}_5\text{H}_7\text{O}_2\text{N}$ for microbial cell matter, show how this compound may be formed from carbon dioxide, water, and ammonia:



In other words, *balance* this equation to show proper proportions of all compounds. Also, elaborate on whether you think this reaction is *exothermic* or *endothermic*.

[file i03705](#)

Question 12

When benzene (C_6H_6) is burned with oxygen (O_2) under ideal conditions, the products are water vapor (H_2O) and carbon dioxide (CO_2). Write a balanced equation showing all reactants and all reaction products in the proper proportions.

Suggestions for Socratic discussion

- Suppose benzene were burned in a “rich” environment (too little oxygen). What other combustion products might form then?

[file i00899](#)

Question 13

Determine the proper number of ethanol molecules and oxygen molecules to combine for complete combustion (the only products being water and carbon dioxide). Express your answer in the form of a balanced chemical equation.

[file i00573](#)

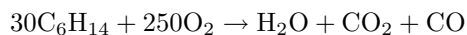
Question 14

Determine the proper number of hydrogen peroxide molecules (H_2O_2) and propane molecules (C_3H_8) to combine for complete combustion (the only products being water and carbon dioxide). Express your answer in the form of a balanced chemical equation.

[file i02414](#)

Question 15

Balance this chemical reaction, showing the combustion of hexane (C_6H_{14}) to produce water vapor, carbon dioxide, and carbon monoxide. Note the quantities of hexane and oxygen already specified in the equation:



Next, calculate the proportions of fuel (hexane) to oxygen which will result in *no* carbon monoxide being formed.

Suggestions for Socratic discussion

- Is carbon monoxide gas (a very *poisonous* substance) produced under *rich* burning conditions or *lean* burning conditions?

[file i00456](#)

Question 16

When hydrogen sulfide gas (H_2S) is burned with oxygen (O_2) under ideal conditions, the products are water vapor (H_2O) and sulfur dioxide (SO_2). Write a balanced equation showing all reactants and all reaction products in the proper proportions.

Also, determine how many moles of oxygen gas will be required to completely combust 15 moles of hydrogen sulfide gas.

[file i00898](#)

Question 17

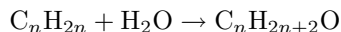
Balance each of the two following chemical reactions, depicting the *incomplete* combustion of methane gas with oxygen:



[file i03706](#)

Question 18

Dow Chemical patented a process for converting olefinic hydrocarbons (molecules having the general formula C_nH_{2n}) into alcohols by combination with water:



Re-write this chemical reaction showing the conversion of ethylene to ethanol, then once again showing the conversion of propylene to isopropanol.

[file i00325](#)

Question 19

If a hydrocarbon fuel is completely mixed with just the right amount of air and thoroughly burned, the only products of combustion will be carbon dioxide (CO_2) and water vapor (H_2O). If the mixing ratio is not stoichiometrically perfect, however, one or the other of the unburned reactants (either fuel or oxygen) will remain after combustion and be detectable in the exhaust gas stream.

Suppose a furnace operates with pure pentane (C_5H_{12}) as the fuel, and the balance of pentane to oxygen in the mix is as follows:



First, determine whether or not this mix is too rich (excessive fuel) or too lean (excessive oxygen). Then, determine what the output signal of an oxygen transmitter located in the exhaust pipe of this furnace will do (*increase, decrease, or remain the same*) if the mix changes to this:



Assume the oxygen transmitter is *direct-acting* (i.e. outputs a greater milliamp signal with greater oxygen concentration).

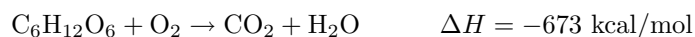
Suggestions for Socratic discussion

- A common product of high-temperature combustion is NO_x emissions (NO , NO_2 , etc.). Explain where the nitrogen comes from to form NO_x compounds, since pentane fuel contains no nitrogen.
- Will NO_x emissions (NO , NO_2 , etc.) in this combustion process increase, decrease, or remain at the same concentration level with the change in air/fuel ratio? Explain why.
- A common method for mitigating NO_x emissions (NO , NO_2 , etc.) is to react the exhaust gases with ammonia (NH_3). Identify the harmless byproducts of a complete NO_x -ammonia reaction.

[file i03638](#)

Question 20

Certain types of microbes (bacteria) facilitate the decomposition of organic matter in such a way that energy may be extracted. One way is *aerobic*, which means the bacteria are supplied with ample amounts of oxygen to metabolize the matter. The basic chemical reaction may be modeled by the oxidation of glucose ($C_6H_{12}O_6$), since this sugar is the base of the starches and cellulose found in plant matter. When glucose is oxidized (aerobic decomposition), the general (unbalanced) reaction is as follows:



Balance this chemical reaction to show the proper proportions of carbon dioxide and water vapor to glucose, and identify whether it is endothermic or exothermic.

A different way microbes may “digest” organic matter is in the absence of oxygen. This is called *anaerobic* decomposition, and the following (unbalanced) reaction shows glucose being converted into carbon dioxide and methane gases:



Balance this chemical reaction as well to show the proper proportions of carbon dioxide and methane to glucose, and identify whether it is endothermic or exothermic. Then, comment on which of these two reaction products is useful as a fuel (to be burned with oxygen).

Suggestions for Socratic discussion

- Explain why the negative ΔH values make sense in light of the fact that both of these reactions are facilitated by *bacteria* in dark environments.

[file i03897](#)

Question 21

One of the byproducts of high-temperature combustion using atmospheric air as the oxidizer is collectively referred to as NO_x : oxides of nitrogen. Nitrogen gas, which comprises the vast majority of the air we breathe, reacts with oxygen at high temperatures to form the following compounds:

- NO
- NO_2
- N_2O_4
- N_2O_5

These oxides of nitrogen can later form nitric acid in the atmosphere, and are a critical component of *smog*. Thus, reducing NO_x emissions in combustion processes is a significant environmental concern.

Oxygen trim control, which minimizes the amount of air drawn in to a combustion process, helps to minimize NO_x production: the less air brought into a fire, the less free nitrogen available, and the less oxygen left after combustion to combine with nitrogen to form NO_x . However, there are combustion processes where oxygen trim is not practical. Diesel and gas turbine engines are two such processes, because their air intake must be unrestricted for maximum thermodynamic efficiency (conversion of heat into mechanical energy).

Another method of NO_x mitigation is *ammonia injection*, sometimes in the form of pure (anhydrous) ammonia gas, other times in the form of *urea* (liquid). In either case, ammonia is sprayed into the exhaust stream of the engine prior to a catalyst, and the resulting chemical reaction reduces NO_x molecules to harmless byproducts.

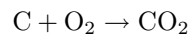
Determine this chemical reaction between ammonia (NH_3) and NO_x , and identify the harmless byproducts produced by it. Then, determine what sort of control system might control the flow of ammonia into the exhaust of an engine. In a vehicle engine control system, where a NO_x sensor installed in the exhaust pipe might be cost-prohibitive, determine what other variables might predict (feedforward) the amount of ammonia flow necessary to neutralize all the exhaust NO_x .

[file i01828](#)

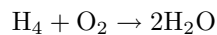
Answers

Answer 1

For each molecule of methane, there is a single atom of carbon (C) and four atoms of hydrogen (H₄). In order to convert one atom of carbon into 1 molecule of carbon dioxide (CO₂), one molecule of oxygen (O₂) is required:



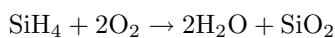
In order to convert four atoms of hydrogen into water, two more atoms of oxygen are required:



Thus, two molecules of O₂ are needed to completely burn one molecule of CH₄. This means, by extension, that two moles of oxygen gas will be required for every one mole of methane. So, if our methane quantity is 1400 moles, our oxygen quantity must be 2800 moles.

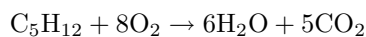
Answer 2

Answer 3

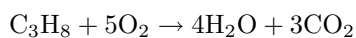


Silicon dioxide is also known as *silica*, and constitutes the mineral *quartz*. This means that a silane fire produces particles of sand in addition to water vapor!

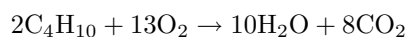
Answer 4



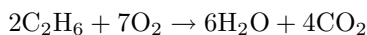
Answer 5



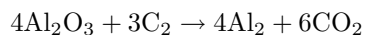
Answer 6



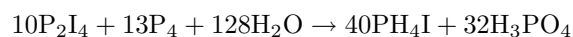
Answer 7



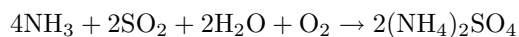
Answer 8



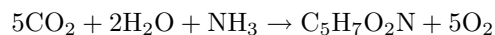
Answer 9



Answer 10

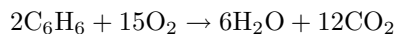


Answer 11

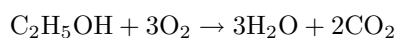


This is definitely an *endothermic* reaction, because both CO_2 and H_2O are highly stable (i.e. low-energy) molecules requiring much energy input to split apart, which is what must happen in order to form the compound necessary to build microbes.

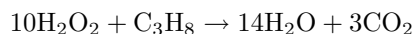
Answer 12



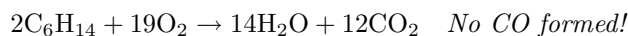
Answer 13



Answer 14



Answer 15

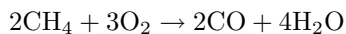


Answer 16

22.5 moles of oxygen (O_2) are necessary to completely combust 15 moles of hydrogen sulfide (H_2S).

Answer 17

Note that the first equation was a bit of a trick: there are *no* molecules of CO_2 produced at this ratio of methane to oxygen!

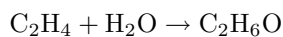


In the second reaction, we have both CO and CO_2 produced, along with water vapor:

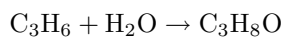


Answer 18

Ethylene to ethanol:

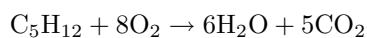


Propylene to isopropanol:



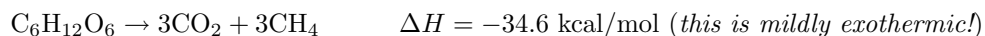
Answer 19

This mixture is **too lean**. The ideal (stoichiometric) pentane-to-oxygen mix is:



If the oxygen content is reduced, the mixture will be closer to ideal, but still too lean. Thus, the oxygen transmitter signal will **decrease** (become closer to 4 mA).

Answer 20



Answer 21

Harmless byproducts: free nitrogen and water vapor.

Follow-up question: write a stoichiometrically balanced chemical reaction for NH_3 and NO_2 , showing how the only byproducts will be nitrogen (N_2) and water vapor (H_2O).