CHAPTER 22 METHANE

METHANE, CH_4, IS A COLORLESS, ODORLESS, flammable gas that burns with a faintly blue flame. ***Natural gas*** used by many North Americans for heating and cooking, is primarily methane (typically 85%). The gas odor is from an added substance so that gas leaks can be detected. Pure methane has no odor. Explosive mixtures of methane with air containing between 5 - 14 % methane. Mixtures containing more than 14% burn without explosion.

Methane occurs widely in nature as a product of anaerobic decay of organic matter and is called "marsh gas". Methane is a major component of the atmosphere of the outer planets.

Methane has a melting point of -182 ^oC and a boiling point of -164 ^oC. Its density, 0.6557 g/L at 25 ^oC and 1 atm, is only 55% that of air. Methane is not very soluble in water (3.5 mL CH_4 per 100 mL water at 17 ^oC and standard pressure), but is fairly soluble in alcohol, ether and many organic solvents.

Methane was first prepared in 1899 by Matthews by the method employed in this chapter — heating sodium acetate with sodium hydroxide:[1]

$$NaOH(s) + NaC_2H_3O_2(s) \rightarrow CH_4(g) + Na_2CO_3(s)$$

Pure methane can be prepared from the combination of pure carbon and hydrogen at temperatures greater than 1100 ^oC. Methane is also produced from the fermentation of sewage and other sludge materials.

Methane is used for heating, cooking and illuminating. It is also used in the manufacture of hydrogen that is subsequently used in the manufacture of ammonia. Methane is used to produce formaldehyde, hydrogen cyanide and numerous organic compounds.

[1] ***J. Amer. Chem. Soc. 21***, 647 (1899)

Suitability

All of the experiments could be performed as a sequence of classroom demonstrations designed to show several important properties of methane and organic compounds. Experiments 1, 3 and 6 are the most suited for student-use in a laboratory situation. Advanced students or students with special laboratory skills could be allowed to perform these experiments under close supervision by the instructor.

Experiment 1. Products of combustion
Experiment 2. How a Bunsen burner works
Experiment 3. Flame chemistry
Experiment 4. Burned rings in paper
Experiment 5. Window screen provides thermal insulation
Experiment 6. Density of methane: Lighter-than-air methane bubbles
Experiment 7. Burning methane. Controlling gas flow by density
Experiment 8. Explosive mixture of methane/air
Experiment 9. Bubble domes
Experiment 10. Big water thrasher
Experiment 11. Reaction with chlorine: Formation of soot

Most of the eleven experiments can be used to address topics such as organic chemistry, combustion of hydrocarbons, products of combustion, household chemicals, chemical reactions, energy and chemical change, and writing balanced chemical equations. Experiments 1 - 5 specifically explore the nature of a methane flame. Experiments 6 – 8 are based on methane's density; it is about half that of air. Experiment 9 has more to do with soap films than methane, but the methane/air mixture is eventually ignited in the experiment. Experiment 10 provides an example of how explosives are used to do useful work. The demonstration is remarkable in that such a very small amount of methane/oxygen will cause a very impressive action: 2 L of water are thrown into the air over 2 m! Experiment 11 is unlike the first ten. Here methane and chlorine react to produce soot and hydrochloric acid.

Background skills required

Students should be:

- able to manipulate syringes from previous experience with the In-Syringe method.
- familiar with the Thermal Method.
- able to measure quantities of reagents using a balance.
- understand fundamental concepts of high school chemistry so that observations can be interpreted.

Time required

If natural gas is used as the source of methane, these experiments can be conducted rather quickly. All eleven experiments are well suited as classroom demonstrations. Making methane by the thermal method is instructive and makes a good laboratory activity. If students do make methane, they could use it to perform one or more of Experiments 1, 3 and 6. They could accomplish that in a single laboratory period.

Before students arrive: Assemble the equipment required

Generating gases by the Thermal Method requires the Microscale Gas Chemistry Kit as well as the special "Thermal Method Equipment" listed on the next page. This chapter features several unique pieces of equipment that should be constructed before the students arrive.

Methane from a gas jet

Laboratory gas jets usually dispense methane or propane, depending on locale. If the school is heated by natural gas, you can assume that you have methane on tap. On the other hand, if there are "LP" tanks behind the school (typically in remote areas or in areas with bedrock near the surface), your gas jets are probably dispensing propane. If you have methane available, it can be used for all of these experiments.

Preparation of methane in the microwave oven

Samples of $CH_4(g)$ also can be prepared conveniently in a microwave oven. See Chapter 24 for details.

Gas reaction catalyst tube

Three interesting reactions involving methane and the Gas Reaction Catalyst Tube were given in Chapter 18. Refer to these catalytic oxidation experiments:

A. Oxidation of methane with air
F. Methane and nitrogen dioxide
K. Nitrous oxide and methane

Website

This chapter is available on the web at website:

http://mattson.creighton.edu/Microscale_Gas_Chemistry.html

Instructions for your students

For classroom use by teachers. Copies of all or part of this document may be made for your students without further permission. Please attribute credit to Professors Bruce Mattson and Mike Anderson of Creighton University and this website.

GENERATING METHANE[1]

General Safety Precautions

Always wear safety glasses. Gases in syringes may be under pressure and could spray liquid chemicals. Follow the instructions and only use the quantities suggested.

Toxicity

Methane is relatively non-toxic; it is a simple asphyxiant. It is flammable in air and forms explosive mixtures with air.

Methane "on tap"

Laboratories equipped with natural gas (not LP gas) may use that gas for all of these experiments. Connect the syringe to the gas jet by using a larger diameter rubber tube that will fit over the gas jet as well as over the outside of the syringe fitting. Gas pressure is not sufficient to push the plunger, however, the gas can be simply withdrawn by pulling outward on the plunger.

Equipment

The following "Thermal Method Equipment" is used to generate gases by the Thermal Method. It is the same equipment that was used to produce HCl(g) in Chapter 19. You will also need the basic Microscale Gas Chemistry kit (Chapter 1)

18 x 150 mm test tube (in addition to the one in the Microscale Gas Chemistry Kit)
two-hole #1 stopper fitted with two short lengths (2 cm) of glass tubing
two pieces of tubing, 1/8-inch (3.175 mm) ID, 5 cm length
pinch clamp or hemostat
ring stand and a suitable clamp to hold test tube
wooden dowel or aluminum rod, 1 cm diameter x 15 cm length with suitable clamp to hold it to the ring stand
three heavy duty rubber bands
small Bunsen burner
matches or a lighter
marker pen
balance capable of measuring to 0.01 g

[1] Content for this chapter first appeared as "Microscale Gas Chemistry, Part 15. Experiments with Methane" Mattson, B. M., Catahan, R., Nguyen, J., Patel, A., Khandhar, P., Mattson, A. and Anand Rajani, A., ***Chem13 News***, **284**, April, 2000.

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MAKING METHANE

Methane is generated by the Thermal Method, described in detail in Chapter 19 and summarized here. The two chemicals to be heated together are sodium acetate and sodium hydroxide.

Chemicals required for each preparation

sodium acetate, $NaC_2H_3O_2$, 2 g
sodium hydroxide, NaOH, 2 g

This quantity of reagents will produce several syringes full of $CH_4(g)$. The reaction is:

$$NaOH(s) + NaC_2H_3O_2 \rightarrow CH_4(g) + Na_2CO_3(s)$$

1. Wear your safety glasses!

2. Check the plunger and barrel

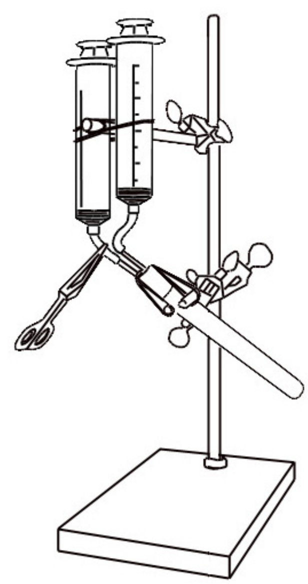
Make sure the syringe plunger moves easily in the syringe barrel. If it does not, try another combination of plunger and barrel.

3. Measure out the reagents

Add 2 g of each reagent together in the 18 x 150 mm test tube.

4. Assemble the apparatus

The fully assembled apparatus is shown at right. Start by clamping the test tube in position at a 45^{o} angle.



5. Secure the stopper in the test tube

Insert the rubber stopper firmly and snugly into the test tube. The stopper is held in place with a rubber band. The rubber band should be taut.

6. Position the syringes

Clamp the wooden dowel or aluminum rod in position about 15 cm above the lower clamp that holds the test tube. The two syringes are held in position by rubber bands around the dowel/rod. The use of rubber bands is preferable to using clamps because it is easier and faster to remove/replace syringes.

7. Burner

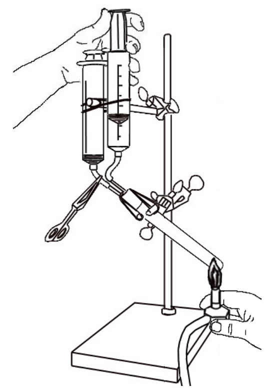
A small Bunsen burner is necessary for this reaction. More heat is required than was the case in the preparation of carbon monoxide in the previous chapter.

8. Hemostat/pinch clamp

A hemostat or pinch clamp is used to pinch closed the left rubber tube.

9. Perform the reaction in three steps

Step A. Collect air and gas in first syringe

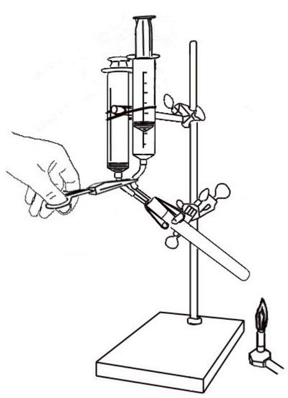


The first of the gas collected is mostly air originally present in the test tube. Hold the heat source with one hand while assisting the movement of the plunger with the other. This maneuver works well with two individuals working together. **Caution**: Do not crimp the tubing!

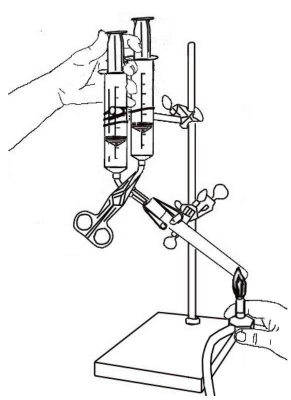
Gently heat while accumulating at least 20 mL waste. Help the plunger upward — maintain reduced pressure. Gas soon will be produced and the plunger of the syringe should begin to move. It may be necessary to assist the sliding movement of the plunger up the barrel of the syringe during the reaction. Continue to heat while gently assisting the plunger's movement.

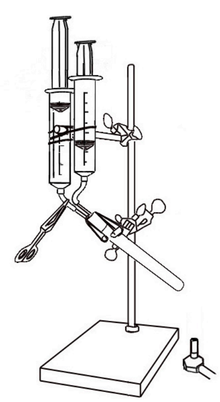
Step B. Collect the gas

After at least 30 mL of waste gas (air) has been collected in the right syringe, switch the location of the pinch clamp (left figure below) to the other rubber tubing so that relatively pure product gas can be accumulated in the other syringe. Assist the movement of the plunger as before (middle figure below). Continue to collect pure gas until at least 50 mL has been collected.



move hemostat





left tube clamped shut

Step C. Stop heating

Switch the pinch clamp back to the tubing connected to the pure gas collection syringe and remove the heat source (right figure, above). ***WARNING:*** Never simultaneously pinch both tubes!

While holding the plunger slightly outward in order to establish slightly reduced pressure, remove the tube from the gas collection syringe and immediately cap the syringe. The syringe contains > 95% pure methane ready for experiments.

Allow the apparatus to cool. The plunger in the remaining syringe may move outward at first because gas generation may continue for several seconds after the test tube is removed from the flame. The plunger may move inward as the apparatus cools.

10. (optional) Collecting multiple samples

It is possible (and probably desirable) to replace the CH_4(g) syringe with a clean, dry syringe, and repeat Steps 2 and 3; numerous syringes full of methane can be collected in this fashion.

11. Washing the gas

It is unnecessary to wash the samples of methane; they can be used as collected.

12. Disposal

Unwanted CH_4(g) samples can be safely discharged into the fume hood or out of doors.

Teaching tips

1. Keep the system under reduced pressure at all times — avoid popping stoppers!
2. The yield of methane is quite impressive. We have collected at least five syringes full of gas before stopping the reaction.

Questions

1. How many moles of $CH_{4(g)}$ can be expected if 2 g sodium acetate and 2 g sodium hydroxide are used in the reaction? Which reagent was limiting? What is the other product obtained?
2. Referring to Question 1, what volume (in mL) of CH_4(g) is expected at 298 K and the standard pressure?
3. What does the gas smell like? Waft some past your nose with your hand. Remember that methane is lighter than air.

4. Air has an average molar mass of 29 g/mol. Use that value and the ideal gas law to determine the density of air. Now, determine the density of methane. What is the ratio of densities, $density_{methane}/density_{air}$?

EXPERIMENTS WITH METHANE

Most of the experiments described here involve the combustion of methane. The reaction is:

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) \qquad \Delta H = -802.3\ kJ$$

EXPERIMENT 1. EXPERIMENT 1. PRODUCTS OF COMBUSTION

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
glass pipet
hemostat or similar screw clamp
125 mL flask
matches or a lighter

Chemicals

$CH_4(g)$, 60 mL (or natural gas source)
limewater (See Appendix D)

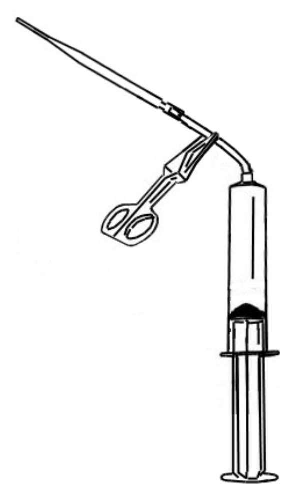
Suitability

advanced high school chemistry lab, university lab, and classroom demonstration

Applications, Topics, Purpose

organic chemistry, combustion of hydrocarbons, products of combustion, household chemicals, chemical reactions, energy and chemical change, writing balanced chemical equations

Instructions



Generate a syringe full of methane. Equip the syringe with a length of tubing, a glass pipet (the tubing fits snugly *inside* the pipet), and the screw clamp. Clamp the hemostat to completely seal the tubing. Using a ring stand and a suitable clamp, clamp the glass pipet in the approximate position shown in the figure. Two people are needed for the next part of this experiment. One person should push gently on the plunger so that the methane is always under pressure. The second person should adjust the hemostat or screw clamp to allow a steady but small flow of methane. Ignite the gas issuing from the pipet. The flame should be no more than 1 cm in height. Position a 125 mL flask over the pipet so that flame is in the center of the flask. Water condensation on the glass will be noted and the flame will go out within seconds due to deprivation of oxygen. Remove the pipet from the flask and close the hemostat or screw clamp. Test the contents of the flask for $CO_2(g)$ by adding 10 mL limewater to the flask and shaking the flask for a few seconds. A cloudy solution indicates the presence of CO_2 as a result of the reaction:

$$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$$

Teaching tips

1. A screw clamp has more sensitivity than the hemostat for fine adjustment.
2. Always remember that methane is lighter than air. Avoid prolonged periods where the syringe cap is off and the syringe opening is directed upward.
3. Remember that methane forms explosive mixtures with air. If there is any chance that the contents of the syringe contain such a mixture, do not attempt this experiment or any similar experiment involving open flames.

Questions

1. Were you able to sustain a flame or did it frequently go out?
2. Why does the flame go out if the flow of methane is too fast?
3. Do all combustion reactions form carbon dioxide?
4. What are the two products of combustion of hydrocarbon materials?
5. How would this reaction differ if the burning gas jet were moved into a flask containing oxygen instead of air?

EXPERIMENT 2. HOW A BUNSEN BURNER WORKS

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
ring stand and clamp
glass pipet (the tubing fits snugly *inside* the pipet)
glass tubing (approx. 10 mm inside diameter and 20 cm length)
aquarium air pump or a second syringe filled with air
two hemostats or screw clamps
matches or a lighter

Chemicals

CH_4(g), 50 mL (or natural gas source)

Suitability

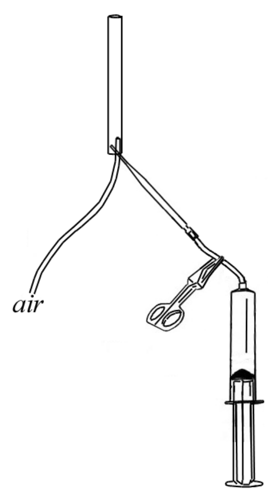
classroom demonstration

Applications, Topics, Purpose

Bunsen burner, organic chemistry, combustion of hydrocarbons, household chemicals, chemical reactions, energy and chemical change, sodium flame color

Instructions

The Bunsen burner works by mixing a hydrocarbon fuel such as methane with air. The principle is simple and can be demonstrated with a simple length of glass or plastic tubing. The same device shown in the figure from Experiment 1 will be used in this experiment.



Clamp a piece of glass tubing in a vertical position. A source of forced air, such as an aquarium air pump or a second syringe filled with air is optional and is used to create a hotter flame. Generate a syringe full of methane. Open the hemostat and start the flow of methane through the "Bunsen burner" tube by applying a continual positive pressure on the syringe plunger. Light the gas at the top of the tube. The flame will be gentle. Start the flow of air. This may blow out the flame if its flow is too great. Use a hemostat or screw clamp on the air delivery tube to reduce the flow of air. When the methane-air mixture is optimal, the flame will be small and sharp and there will be an audible noise. Interestingly, methane prepared as described above will burn with an orange-yellow flame due to trace levels of suspended sodium salts in the gas. These can be removed by washing the methane (draw 5 mL distilled water into methane-filled syringe and shake) after which the methane burns with its characteristic blue flame.

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Teaching tips

1. This experiment works especially well if natural gas is used. Instead of using a syringe to dispense the methane, the tubing can be connected directly to the gas jet.

2. The flame can sometimes move inside the glass tube. This is not a problem.

Questions

1. How does the flame change if the flow of methane is increased or decreased?

2. How does the flame change if the flow of air is increased or decreased?

3. Why does pure methane (without air around) not burn?

4. What did Bunsen's burner design accomplish?

5. Did you notice the yellow color due to sodium in the glass? How is it possible that sodium colors the flame?

EXPERIMENT 3. FLAME CHEMISTRY

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
matches or a lighter
Bunsen burner
glass tubing (approx. 10 mm inside diameter and 20 cm length)
piece of glass tubing (5 mm ID x 8 cm length)
glass pipet
hemostat or screw clamp
ring stand and clamp

Chemicals

CH_4(g), 50 mL (or natural gas source)

Suitability

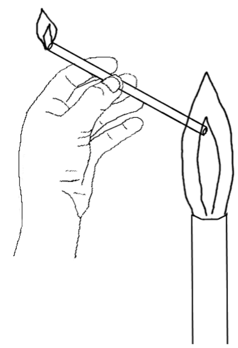
high school chemistry lab, university lab, and classroom demonstration

Applications, Topics, Purpose

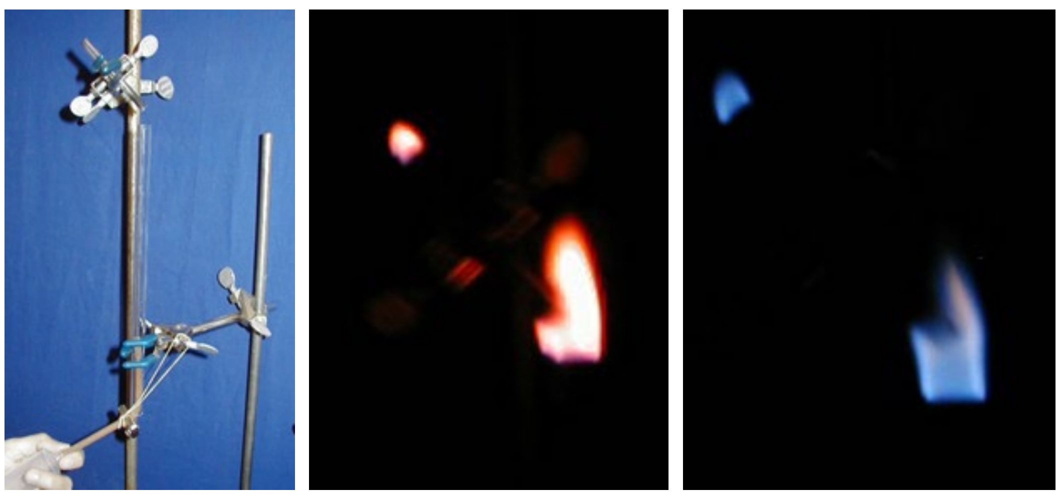
organic chemistry, combustion of hydrocarbons, household chemicals, chemical reactions, energy and chemical change, nature of a flame

Instructions

Most chemistry textbooks describe the chemistry of the flame, a fascinating subject that was first investigated by Michael Faraday and described in his ***The Chemical History of the Candle*** lectures that he gave at the Royal Institution during the early and mid-19th century.[2] Faraday demonstrated that *"…there are clearly two different kinds of action — one of the production of the vapor, and the other the combustion of it — both of which take place in particular parts of the candle."* The former is now called the pyrolysis zone, where the fuel is broken into radicals (such as H atoms and CH_3 groups) and smaller molecules including $H_2(g)$. The outer region contains air and is called the combustion zone. In this experiment we will repeat this experiment of Michael Faraday's using methane rather than a candle flame and the "Bunsen burner" constructed in Experiment 2. The air pump is not used for this experiment. A smaller piece of glass tubing should be held by a clamp in a 45° position about 2 - 3 cm above the opening of the burner as shown in the figure.



Prepare several syringes full of methane. Two people are required to perform this experiment. One person delivers the methane through the main burner in a continuous, steady stream and ignites the gas issuing from the top. The flame should be large enough that the small tube is positioned towards the top of the flame. Gases diverted into the tube are incompletely combusted and can be ignited by the second person as they issue from the opening.



Teaching tips

1. This experiment works especially well if natural gas is used. Instead of using a syringe to dispense the methane, the tubing can be connected directly to the gas jet.
2. A "regular" Bunsen burner can also be used and is probably easier. Adjust it to a cool flame.

[2] ***Faraday's Chemical History of the Candle. Twenty-two Experiments and Six Classic Lectures***, Chicago Review Press, Distributed by Independent Publishers Group, ISBN 1-55652-035-2. Bibliographic information about the lives of Michael Faraday and Sir Humphrey Davy are also available at the web site of the Royal Institution of Great Britain: http://www.ri.ac.uk/History/

Questions

1. What part of the flame contains the pure "fuel" — the inner cone (pyrolysis zone) or the outer cone (combustion zone)?
2. Which zone do you think would be the hotter of the two?
3. Would the experiment work if you drew gases from the outer cone? Try it.

EXPERIMENT 4. BURNED RINGS IN PAPER

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
matches or a lighter
heavy-stock paper such as a note card
glass tubing (approx. 10 mm inside diameter and 20 cm length)
glass pipet
hemostat or screw clamp
ring stand and clamp

Chemicals

CH_4(g), 50 mL (or natural gas source)

Suitability

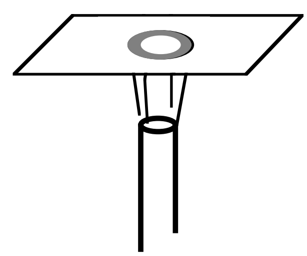
classroom demonstration

Applications, Topics, Purpose

organic chemistry, combustion of hydrocarbons, household chemicals, chemical reactions, energy and chemical change, nature of a flame

Instructions

This is another experiment described by Faraday for the candle. Here we will use methane and the burner (without the air pump) built in Experiment 2. CAUTION! Have a cup of water ready in case the paper used in this experiment catches on fire. While one person operates the burner and methane-filled syringe, a second person holds a piece of heavy-stock paper such as a note card positioned horizontally through the inner cone as shown in the figure — approximately 2 cm above the top of the burner. Within a few seconds, the paper card will begin to burn (turn brown) in a ring. As soon as the brown ring appears, remove the card; do not allow the paper to actually ignite. This experiment supports the fact that the pyrolysis zone is cool and the combustion zone is hot.



Teaching tips

1. This experiment works especially well if natural gas is used. Instead of using a syringe to dispense the methane, the tubing can be connected directly to the gas jet.

2. A “regular” Bunsen burner can also be used and is probably easier. Adjust it to a cool flame.

3. Hold the card in the flame only briefly; it easily catches fire.

Questions

1. In the previous experiment, you answered the questions “Which zone do you think would be the hotter of the two?” With the results of this experiment, was your initial answer proved or disproved?

2. Sketch the cross section of a flame and label the pyrolysis and combustion zones.

3. How would the experimental results differ if you held the card closer to the burner? Closer to the tip of the flame? Try it.

EXPERIMENT 5. WINDOW SCREEN PROVIDES THERMAL INSULATION

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
window screen, 5 cm x 5 cm, 2 pieces
glass pipet (the tubing fits snugly *inside* the pipet)
glass tubing
hemostat or screw clamp
matches or a lighter
ring stand and clamp

Chemicals

$CH_4(g)$, 2 x 50 mL (or natural gas source)

Suitability

classroom demonstration

Applications, Topics, Purpose

mine safety, heat sinks, heat conduction, combustion of hydrocarbons, chemical reactions, energy and chemical change, nature of a flame

Instructions

As a final experiment from Faraday's work with candles, we will investigate how a piece of window screen will affect the flame when it is held in a position similar to that of the paper card in the previous experiment. It works best to hold the screen in position 2 cm above the burner. Do not use the air pump.

Part A.

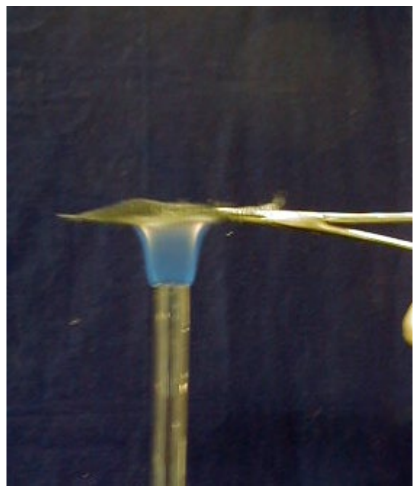
While one person discharges the methane-filled syringe through the burner tube, a second person holds the screen and ignites the gases above the screen. Will the flame jump through the screen and start burning below?

Part B.

While one person discharges the methane-filled syringe through the burner tube, a second person holds the screen and ignites the gases *below* the screen. Will the flame jump through the screen and start burning above?

Part C.

Holding two screens 2 and 4 cm above the burner, the gases between the screens can be ignited. The screen's ability to dissipate heat and prevent combustion while allowing flammable mixtures of gases to pass through has been used in practical applications. Sir Humphrey Davy used this principle in his invention of the miner's safety lamp in 1815. Flammable gases from the mine could pass through the screen and burn in the enclosed flame with a “colored haze” while the screen prevented the open flame from causing a mine explosion.[2]


Teaching tips

1. This experiment works especially well if natural gas is used. Instead of using a syringe to dispense the methane, the tubing can be connected directly to the gas jet.
2. A “regular” Bunsen burner can also be used and is probably easier. Adjust it to a cool flame.

Questions

1. Did the flame ever jump through the screen to start burning on the other side?
2. Could you ignite the gas above and below the screen at the same time?
3. When the flame exists below the screen, is all the fuel consumed, or does some of it get through the screen? Explain your reasoning.

[2] Photo of the miners' safety lamp is from the web site (History page) of the Royal Institution of Great Britain.

EXPERIMENT 6. DENSITY OF METHANE: LIGHTER-THAN-AIR METHANE BUBBLES.[3]

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
large bulb polyethylene transfer pipet
scissors
candle affixed to a coin
matches or lighter

Chemicals

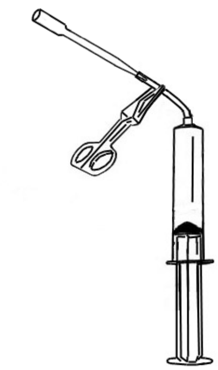
CH_4(g), 50 mL (or natural gas source)
3% dish soap solution

Suitability

high school lab, university lab, and classroom demonstration

Applications, Topics, Purpose

gas density, organic chemistry, combustion of hydrocarbons, household chemicals, chemical reactions, energy and chemical change, nature of a flame



Instructions

Methane is 45% lighter than air, so bubbles of the gas rise. Single bubbles of suitable size are easily generated by the device shown in the figure. A large bulb polyethylene transfer pipet is connected to a methane-filled syringe with a 2 cm length of tubing. The bulb of the pipet is cut off with a scissors.

Making the bubbles: Dip the mouth of the pipet into a 3% dish soap solution. A film of soap will cover the opening. Start forming the bubble while directing the pipet's mouth downward so the bubble forms below the device. This allows extra soap solution to gather at the bottom of the bubble as it is forming. While the bubble is still small, a slight shake will dislodge the extra drop which otherwise could make the bubble heavier-than-air. Quickly fill the bubble with the 60 mL gas while tilting the device to a horizontal position. Dislodge the bubble with an abrupt downward flick of the pipet. The bubble may rise, stay suspended in air or slowly drop depending on the amount of methane compared to the mass of the soap film. Bubbles containing 60 mL methane usually rise. The bubbles can be ignited with a candle. They will produce a fireball about 20 cm in diameter and represent about 2 kJ of heat. USE CAUTION!

[3] Based on ***Spectacular Gas Density Demonstration Using Methane Bubbles***, R. Snipp, B. Mattson, and W. Hardy, ***Journal of Chemical Education***, 1981, **58**, 354.

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Teaching tips

1. This experiment works especially well if natural gas is used. Instead of using a syringe to dispense the methane, the tubing can be connected directly from the gas jet.

2. This reaction can be scaled up with impressive results. See the reference given as a footnote to the previous page.

Questions

1. Describe your experimental observations for this reaction.

2. Why do the smaller bubbles drop and the larger ones raise in air?

3. Estimate the diameter of a bubble. Calculate the volume of the bubble in units of mL. Estimate the number of moles of methane in the bubble by using the ideal gas law and making appropriate assumptions as needed.

4. Given the heat of combustion for methane (provided as a prelude to these experiments), estimate the amount of heat released if one were to ignite the methane bubble considered in the previous question.

EXPERIMENT 7. BURNING METHANE. CONTROLLING GAS FLOW BY DENSITY

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
large test tube (22 x 200 mm)
candle affixed to coin
matches or lighter

Chemicals

CH_4(g), 2 x 60 mL (or natural gas source)

Suitability

university lab and classroom demonstration

Applications, Topics, Purpose

gas density, organic chemistry, solubility in non-aqueous solvents, combustion

Instructions

Fill a large test tube with methane using water displacement. The volume of the test tube is 80 mL so two syringes full of methane will be necessary. Darken the room. Remove the test tube from the water and continue to hold the test tube with its mouth directed downward. Bring a burning candle up to the mouth of the test tube and the gas will begin to burn. In order to maintain the flame and burn all of the gas, the test tube must be rotated to a 45^{o} angle position with open end up so that the lighter-than-air methane can leave the test tube. The gas will burn down the test tube in the form of a narrow, bright blue disk that produces condensation on the glass just above the flame. It takes approximately 15 seconds for the burning disk of methane to burn to the bottom of the tube. CAUTION: The test tube will become hot.

Teaching tips

1. The test tube becomes hot, but not too hot to hold. Use of a clamp or insulated gloves to hold the test tube would alleviate this problem.
2. The test tube can be rotated to increase/decrease the rate of combustion and the appearance of the fire.

Questions

1. In what other experiments did the density of methane play a role?
2. Describe the fire ring. Why did it move down the tube?
3. The product of combustion is carbon dioxide and water and methane needs oxygen to burn. Sketch two test tubes and label all four gases (a) early in the process and (b) later in the process when the flame has worked its way into the test tube. Use arrows to show the flow of each gas.

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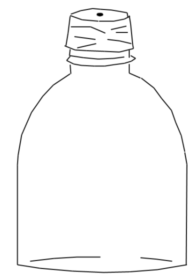
EXPERIMENT 8. EXPLOSIVE MIXTURE OF METHANE/AIR

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
20-ounce (600 mL) plastic soft-drink container
aluminum foil, 5 cm x 5 cm
ring stand and clamp
matches or lighter

Chemicals

$CH_4(g)$, 2 x 50 mL (or natural gas source)



Suitability

classroom demonstration

Applications, Topics, Purpose

explosive mixtures, physical and chemical changes and properties, energy and chemical change

Instructions

Methane forms explosive mixtures with air in the 5 - 14% range. This can be demonstrated with the device shown in the figure, made by cutting a 2 L plastic soft-drink container in half. Cover the opening with a small piece of aluminum foil. With a sharp pencil, poke a hole of approximately 4-mm diameter in the center of the foil. Clamp the device in the position shown in the figure. Close the hole with a rubber stopper or similar object over the hole for the moment.

Generate a least two syringes full of methane and transfer the gas to the device from the bottom. Position the syringe's delivery tube so that most of the gas accumulates near the top of the device. Remove the object covering the hole and immediately ignite the gas. As demonstrated in the previous two experiments, methane is lighter than air and will burn with a large flame as it passes through the hole in the foil. When much of the methane has been consumed and the methane/air mixture falls to 14%, the gas mixture will explode downward into the container. The "explosion" is quite gentle (unlike hydrogen-air), but demonstrates an important principle. The demonstration should be repeated in a darkened room.

Teaching tips

1. This experiment works especially well if natural gas is used. Instead of using a syringe to dispense the methane, the tubing can be filled directly from the gas jet.
2. The hole must be fairly large — 4 mm diameter.

Questions

1. Describe your observations. Did gas density play a role in this experiment?
2. Sketch the apparatus and label all the four gases, CH_4, O_2, CO_2 and H_2O. Use arrows to show the flow of each gas.
3. Why did the methane suddenly "explode"?

EXPERIMENT 9. BUBBLE DOMES

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
250 mL glass beaker
strip of cloth
match or lighter
large plastic weighing dish

Chemicals

CH_4(g), 50 mL (or natural gas source)
3% dish soap solution

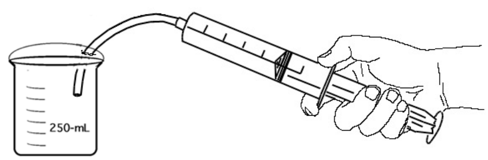
Suitability

classroom demonstration

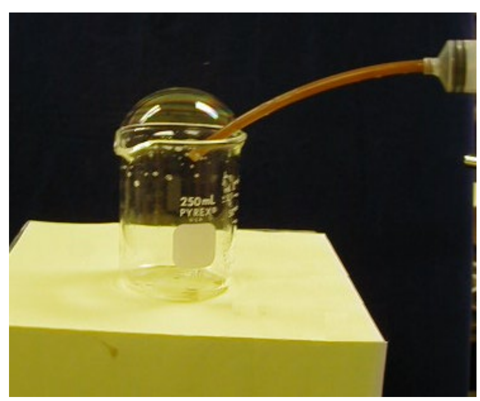
Applications, Topics, Purpose

household products, surface tension, soap, solutions

Instructions



Soap film domes can be made from 3% dish soap solution and a strip of cloth. Soak the cloth in the soap solution. Then starting from one side of a 250 mL beaker, slowly drag the cloth across the top of the beaker forming a film of soap. Without drafts, the film will remain intact for as long as a minute. Fill a syringe with methane and equip the syringe with a 15 cm length of tubing. Moisten the tubing with the soap solution and insert the tubing through the soap film. When moistened, the tubing will not break the film. Quickly inject the methane; it will cause the film to mound up forming a bubble as shown in the figure. Remove the tubing and ignite the bubble with a candle. [Hint: Sometimes an unwanted second bubble forms at the end of the tubing while the methane is being injected. To prevent this, initially withdraw the plunger about 5 mL in order to break the film over the end of the tubing.]



Teaching tips

1. This experiment works especially well if natural gas is used. Instead of using a syringe to dispense the methane, the tubing can be connected directly from the gas jet.
2. The tubing must be moistened with dish soap. The bubble will burst as soon as a dry portion of the tubing touches the soap film.

Questions

1. Why does the bubble not break when touched by the tubing?

2. Could you poke your finger, moistened with dish soap, through the soap film like the tubing did? (Try it.)

3. How does water behave differently when soap has been added?

EXPERIMENT 10. BIG WATER THRASHER

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment (see list)
35-mm film canister
2 L plastic bottle
empty piezoelectric lighter
large finishing nail
Bunsen burner
hot-glue gun
paper clip

Chemicals

CH_4(g), 30 mL (or natural gas source)
O_2(g), 30 mL (Chapter 4)

Suitability

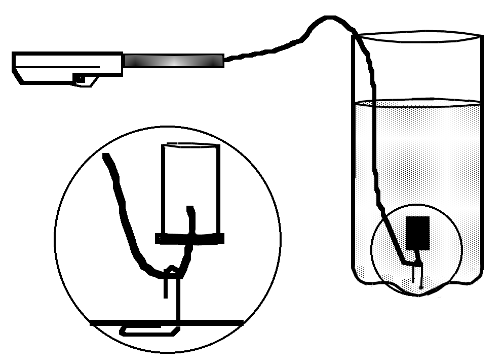
classroom demonstration

Applications, Topics, Purpose

explosive mixtures, physical and chemical changes and properties, energy and chemical change

Instructions

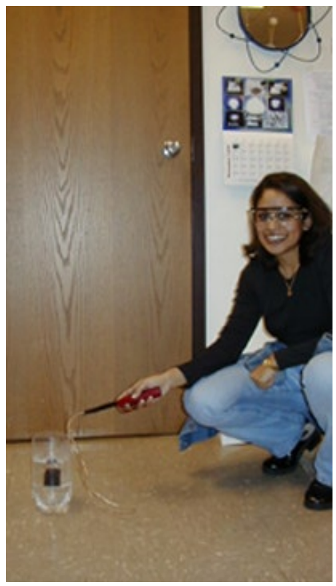
This device, built from a 35-mm film canister, a 2 L plastic bottle and an empty piezoelectric lighter allows the demonstrator to explode small amounts of methane-oxygen mixtures under water. The explosion produced throws the water more than 2-m into the air!



Constructing the device

Construct a piezoelectric sparker from an empty piezoelectric lighter and a 1-m length of stereo wire exactly like was done for the piezo sparker except that the wire is considerably longer. (See Appendix C.) With a metal object (such as a nail) heated in a flame, melt a hole in the cap of a 35-mm film canister of the same diameter as the stereo wire. Insert the wire through the cap into position as shown in the insert figure and hot-glue in place. Test the piezoelectric sparker to assure that it works. A small blue spark should be noticed at the end of the stereo wire. Cut the top off of a 2 L soft drink plastic beverage bottle. Unfold a paper clip but leave one bend intact. Warm the straight end in a flame and push the hot metal through bottom of the 2 L bottle (from the inside). Bend the protruding wire 90º as shown in the figure. The hole will slowly drip water but should not interfere with the experiment.

Prepare a syringe full of methane and another full of oxygen. With a short length (2 cm) of tubing, transfer 20 - 30 mL methane and 30 - 40 mL oxygen to a clean syringe. Allow the gases to mix for a few minutes. (A small object such as a vial cap placed inside the syringe facilitates mixing.) Remove the cap from the film canister and transfer about 30 mL gas mixture to the canister while holding the canister open-end down (methane is lighter than air). Immediately cap the canister with the cap/wire. This transfer is done in air (water displacement does not work because the end of the wire gets wet). Loop the stereo wire around the paper clip hook and fill the 2 L bottle with water. Stand back from the mouth of the bottle and discharge a spark. The explosion is not loud, but always makes a watery mess — plan ahead.



Teaching tips

1. Water will be thrown straight up but will splash everywhere. Makes a good outdoor demonstration.

2. A number of things can go wrong with this demonstration. The wire can become wet and refuse to spark or the gas mixture may not be right. Perseverance will be worth it, however.

Questions

1. Why did the explosion shoot the water out of the 2 L container?

2. What was is the volume of the film container? Calculate the amount of energy produced by using estimates of the moles of methane and oxygen.

3. What conditions are required for an explosion to occur? (It is important to know what these are so that they can be avoided.)

4. People are warned not to get back in their cars while fueling them because of the risk of an explosion. Comment on this risk.

EXPERIMENT 11. REACTION WITH CHLORINE: FORMATION OF SOOT

Equipment

Microscale Gas Chemistry Kit
Thermal Method Equipment
Bunsen burner
tongs
lighter or matches
large text tube (22 x 200 mm)

Chemicals

CH_4(g), 30 mL (or natural gas source)
Cl_2(g), 60 mL (Chapter 16)
3 cm length of Mg ribbon
universal indicator solution
few drops 1 M Ag^+(aq)

Suitability

classroom demonstration

Applications, Topics, Purpose

organic chemistry, reaction mechanism, reaction pathway, energy and chemical change, chemical formulas, chemical formulas, chemical reactions, writing balanced chemical equations, oxidation-reduction reactions

Instructions

Prepare a syringe full of Cl_2. Have ready for use: a lit burner, a 3 cm length of Mg ribbon and tongs. Equip both the Cl_2-filled syringe and the CH_4-filled syringe with separate 15 cm lengths of tubing. Position both tubes all the way to the bottom of a large test tube. Simultaneously discharge both gases into the test tube. Remove the tubes. Without delay, ignite the magnesium ribbon with the burner flame and drop it inside the test tube. The light will initiate a reaction between methane and chlorine, producing soot and HCl:

$$CH_4(g) + 2\ Cl_2(g) \rightarrow 4\ HCl(g) + C(s)$$

Various amounts of soot will be produced. Add water to the test tube and test the pH using universal indicator solution. Finally, test for chloride with Ag^+(aq).

Teaching tips

1. There is a large energy of activation that is provided by the burning magnesium. A mechanism involving radicals (molecular fragments such as H·, CH_3·, and Cl·) is likely at work here.

2. Provide a chart of indicator color vs. the corresponding pH to your students.

Indicator Colors		
pH	**Universal**	**Red Cabbage**
4.0	Red	Red
5.0	Orange Red	Purple
6.0	Yellow Orange	Purple
7.0	Dark Green	Purple
8.0	Light Green	Blue
9.0	Blue	Blue-Green
10.0	Reddish Violet	Green
11.0	Violet	Green
12.0	Violet	Green
13.0	Violet	Green-Yellow
14.0	Violet	Yellow

Questions

1. Can this reaction be thought of as an oxidation/reduction?

2. What are the pieces of evidence that the reaction occurred as shown in the equation above?

3. Would methane and chlorine react to give different products if they were allowed to react under milder conditions? Refer to Chapter 21, Experiment 8. Ethene reactions with chlorine.

Other Experiments with Methane

In this chapter we have presented experiments and techniques that have features unique from previous experiments. Because of methane's combustible properties, a number of experiments previously described can be accomplished with methane as the combustible material. In particular, in Chapter 4 of this series, we described the H_2/O_2 pipet rocket, the H_2/O_2 mini-sponge shooter and H_2/O_2 soap bubbles ("Dynamite soap"). These three reactions also work exceedingly well with methane-oxygen mixtures.

Clean-up and storage.

At the end of the experiments, clean the syringe parts, caps and tubing with water. Rinse all parts with distilled water if available. Be careful with the small parts because they can easily be lost down the drain. **Important:** Store plunger out of barrel unless both are completely dry.

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Summary of Materials and Chemicals Needed for Chapter 22. Experiments with methane

Equipment required

Item	For demo	For 5 pairs	For 10 pairs
Microscale Gas Chemistry Kit (See Chapter 1)	1	5	10
Thermal Method Equipment	1	5	10
top-loading balance	1	2 - 3	3 – 5
pipet, glass Pasteur	2	10	20
125 mL flask	1	5	10
glass tubing*	1	5	10
glass tubing **	1	5	10
extra large body polyethylene disposable pipets	1	5	10
hemostat or screw clamps (additional)	1	demo	demo
aquarium air pump	1	demo	demo
large test tube (22 x 200 mm)	1	demo	demo
250 mL glass beaker	1	demo	demo
large plastic weighing dish	1	demo	demo
Bunsen burner	1	demo	demo

* approx. 10 mm inside diameter and 20 cm length
** approx. 5 mm inside diameter and 8 cm length

Materials required

Item	For demo	For 5 pairs	For 10 pairs
matches or a lighter	1	1	1
candle	1	5	10
tongs			
heavy-stock paper such as a note card	1	demo	demo
window screen, 5 cm x 5 cm	2	demo	demo
aluminum foil, 5 cm x 5 cm	1	demo	demo
20-ounce (600 mL) plastic soft-drink container	1	demo	demo
strip of cloth	1	demo	demo
large finishing nail	1	demo	demo
35-mm film canister	1	demo	demo
hot-glue gun	1	demo	demo
paper clip	1	demo	demo
2 L plastic bottle	1	demo	demo
empty piezoelectric lighter	1	demo	demo

Chemicals required

Item	For demo	For 5 pairs	For 10 pairs
sodium acetate, $NaC_2H_3O_2$*	5 g	25 g	50 g
sodium hydroxide, NaOH*	5 g	25 g	50 g
3% dish soap solution	5 mL	25 mL	50 mL
limewater (See Appendix D)	5 mL	25 mL	50 mL
hydrogen peroxide, H_2O_2, 6%	10 mL	demo	demo
potassium iodide, KI	0.5 g	demo	demo
chlorine, $Cl_2(g)$**	60 mL	demo	demo
magnesium, Mg ribbon	3 cm	demo	demo
universal indicator	2 mL	demo	demo
silver nitrate, 1 M $AgNO_3$	few drops	demo	demo

* This is enough for several preparations of methane. These chemicals are not needed if natural gas is used

** a. prepare chlorine by one of the methods described in Chapter 16

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