The University of Texas at Austin
Department of Chemistry
College of Natural Sciences

Alcohol Cannons

Performer's Version

Safety Hazards

- Personal Protective Equipment:
  - Safety glasses/goggles
  - Nitrile gloves
  - Chemical & flame retardant lab coat
  - Fire extinguisher
- Physical Hazards
  - Utilizes an open flame; may cause serious burns to skin.
  - Methanol, ethanol, and isopropanol are highly volatile and flammable liquids/vapors
  - Propane is an extremely flammable gas.
- Chemical Hazards
  - Methanol is toxic if swallowed, if in contact with skin, and if inhaled; causes damage to organs
  - Ethanol causes serious eye irritation.
  - Isopropanol causes serious eye irritation and may cause drowsiness or dizziness
  - Propane may displace oxygen and cause rapid suffocation.

Materials

- 3 empty, dry 5 gallon water jugs
- Propane blowtorch
- 40 mL of methanol
- 40 mL of ethanol
- 40 mL isopropanol

Safety Data Sheet(s)

- Methanol
- Ethanol, 200 proof
- Isopropanol
- Propane

Procedure

1. Pour the entire 40 mL of alcohol into its designated 5 gallon water jug. Immediately cover the opening with a gloved hand (your non-dominant hand is recommended), making a tight seal.
2. Keeping your hand sealing the top of the jug, pick up the entire plastic jug such that the jug is horizontal. One hand should be sealing the top, while the other is on the flat bottom of the jug.
3. Start swirling the jug so that the alcohol moves along the walls of the jug due to the induced centrifugal force. Again, be sure to keep the opening covered!
   a. *Note: Have fun with this motion (make it big and expressive). The whole point is to get as much of the alcohol as you can into vapor, so the more motion the better.*
4. Make sure you invert the bottle several times so that liquid is forced to coat the neck of the bottle. Your glove will become wet as well.
5. Place the jug back on the tabletop right-side up with your hand still covering the opening. At this point, you should feel the vapor pressure pushing against your palm.
6. Make sure you have your ignition source ready.
   a. *Note: Do not use your wet glove to touch the ignition source!*
7. Quickly remove your hand from the opening, moving it far from the ignition source. Touch your ignition source to the top of the opening, lighting the alcohol vapor and step back.

Pedagogy & Supplemental Information

Thermodynamics surrounds us every day, and is a crucial part of the world as we know it. Thermodynamics in chemistry focuses on the relationship between chemical energy and other forms of energy, like heat and work. The thermodynamics of a given reaction can predict whether or not that reaction will occur under certain conditions, what energy will be released or gained in one form or another by the chemical system in question, and how that energy disperses.

There are a couple of basic thermodynamic properties that we know intrinsically, from life experience. When we hear the word combustion, we typically think two things: it's *hot* and once it starts, it's *going*. Combustion reactions include how handheld lighters work, how the engines of cars, planes, and rockets are powered, and even how you turn on your gas stove. Working within the thermodynamic frame of mind, we know implicitly that a combustion reaction is *exothermic* and *spontaneous* – heat-releasing and self-continuing.

In technical terms, a combustion reaction is one in which a substance (the "*fuel*") reacts with oxygen gas or another strong oxidant to form water and a product dependent on the elemental composition of your fuel. For carbon-based fuels, we see the generation of carbon-based products like carbon monoxide, carbon dioxide, and even solid carbon in incomplete combustion reactions. Other fuels – including ones based in sulfur or nitrogen – exist too. The archetypal combustion reaction is a carbon-based fuel, like an alkane or alkanol, reacting with oxygen gas to produce carbon dioxide and water. In this demonstration, we observe the combustion reactions of three alkanols: methanol, ethanol, and isopropanol.

$2CH_3OH\ (\ell) + 3O_2\ (g) \rightarrow 2CO_2\ (g) + 4H_2O\ (g)$ *Methanol,* $\Delta H_c^o \approx -723$ *kJ/mol*

$C_2H_5OH\ (\ell) + 3O_2\ (g) \rightarrow 2CO_2\ (g) + 3H_2O\ (\ell)$ *Ethanol,* $\Delta H_c^o \approx -1367$ *kJ/mol*

$2C_3H_7OH\ (\ell) + 9O_2\ (g) \rightarrow 6CO_2\ (g) + 8H_2O\ (\ell)$ *Isopropanol,* $\Delta H_c^o \approx -2006$ *kJ/mol*

Going from methanol to isopropanol, each alcohol has an additional carbon (and the subsequent hydrogens necessary to complete their octets). As each molecule gets larger from an increasing number of atoms, the standard enthalpy of combustion (ΔH_c^o) – or the energy released as heat under constant pressure and at STP – grows progressively larger in magnitude. This can be attributed to more bonds per molecule of fuel being *broken* and also more bonds *formed* with greater quantities of products. With each fuel having more atoms, more enthalpy per mole reaction occurs. With these fuel molecules, each one has more atoms overall than the previous – and makes more products per one mole of fuel than the one before it. This change mostly boils down to having a greater net difference in the enthalpy of the products and the reactants; breaking up the reactants requires an *input* of energy aimed to overcome the stabilizing force of chemical bonds, and making products *releases* energy as new, energy-lowering bonds are formed. This can be very clearly observed using this demonstration – methanol combusts most weakly of the three, ethanol combusts more readily, and isopropanol combusts the most fervently. While there are many factors actually at play when digging into the combustion of different alkanols – thermodynamic versus kinetic control, enthalpy of combustion *per carbon*, complete and incomplete combustion reactions, and more – the foundational explanation lies within the bond energies as the size of our fuel molecule grows. That chemical energy stored in each and every bond contributes to how much energy will be inputted and released – and just how vigorous of a fire we get to see!

VOLUNTEERS ALLOWED

Volunteers can 'whoosh' the alcohols inside the jugs while wearing proper personal protective equipment (PPE). Volunteers are not permitted to ignite the alcohols, but can assist in vaporizing them.