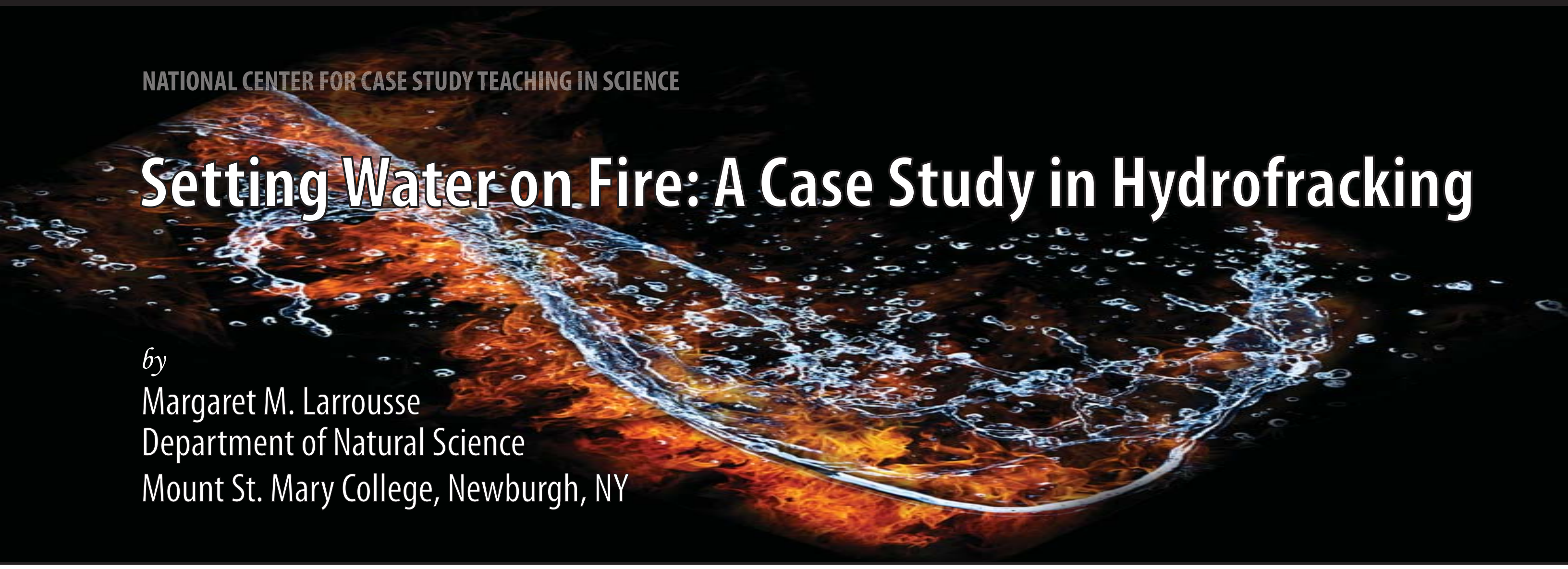

NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Setting Water on Fire: A Case Study in Hydrofracking

by
Margaret M. Larrousse
Department of Natural Science
Mount St. Mary College, Newburgh, NY

Part I – Hoax?

Steve came to chemistry class with a news story he had seen the previous evening that he was eager to ask Professor Donatello about.

"I saw a television program last night about hydrofracking and they showed people setting their water on fire. I think it was a hoax. How can you set water on fire? Water puts out fires!"

Professor Donatello was familiar with hydrofracking. She was keeping up with the controversy in her home state of New York. She knew there was a lot of chemistry involved with the topic and thought that it would be a good opportunity to give the students a research assignment. "Well, Steve, before we answer those questions, maybe we should get some more information about hydrofracking."

Below are the five questions the students were asked to research.

Questions

1. What is hydrofracking?
2. What is methane?
3. What is the boiling point of methane?
4. What is biogenic methane and what is thermogenic methane?
5. What are three advantages and three disadvantages of hydrofracking?

Part II – How to Frack

The next day Steve and the other students came back with the information they had been asked to research.

Steve shared what he had learned with the class about how hydrofracking is a way of extracting methane out of rock like shale. It uses chemicals and water under high pressure to fracture the rock and release the methane. Methane is a molecule that has four hydrogens covalently bonded to a carbon atom. It reacts with oxygen to produce carbon dioxide and water and releases energy in the form of heat. Steve had read that the chemicals and methane have the potential to reach people's drinking wells—and that many of these substances are toxic.

"Nice job, Steve," said Professor Donatello. "I've brought in a diagram for us to look at that shows how hydrofracking is done. As you can see, pumping water and chemicals under high pressure breaks up the rock and releases the natural gas. This makes it available for our use. As you also can see, methane can be released into the atmosphere. In addition to health issues from breathing methane, methane is a very powerful greenhouse gas, but that's a story for another day."

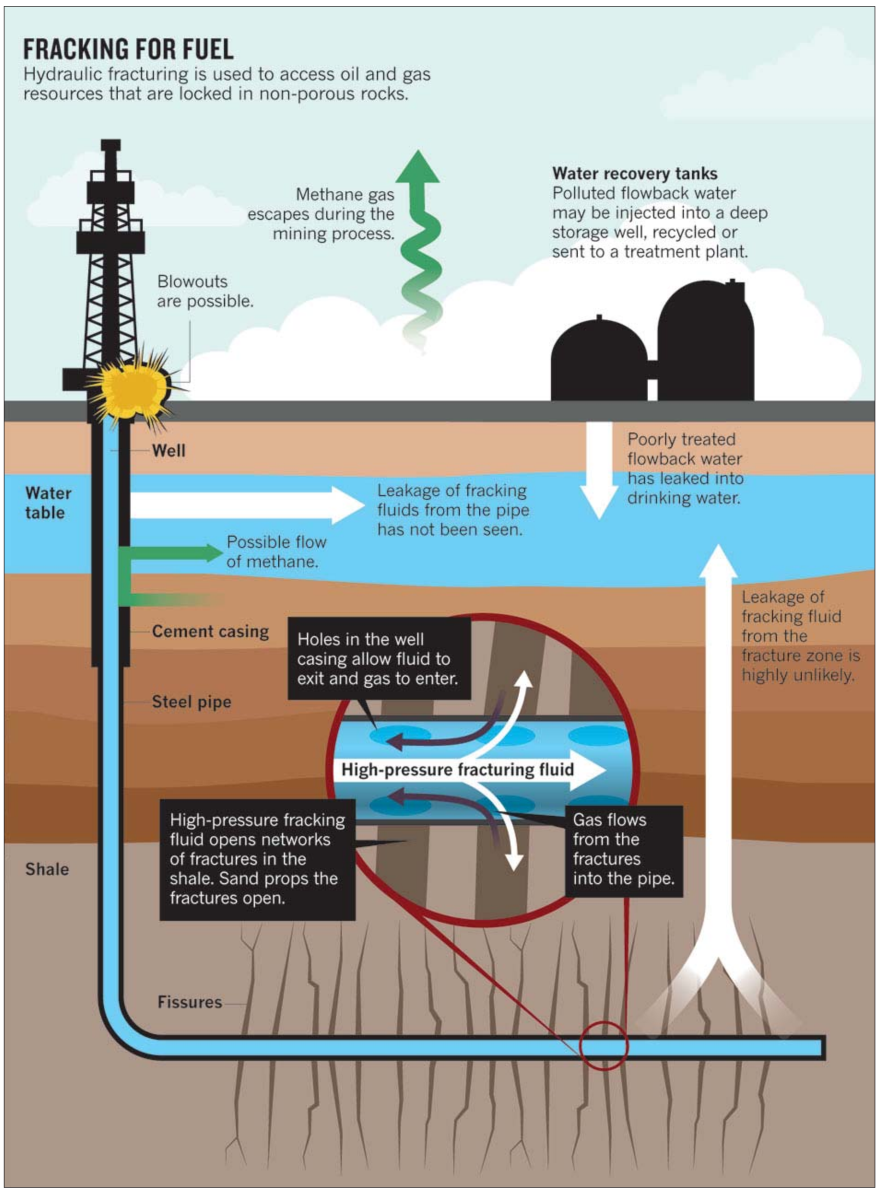

Figure 1. Fracking for Fuel. *Source:* "Natural gas: Should fracking stop?" by R.W. Howarth, A. Ingraffea, & T. Engelder. Reprinted by permission from Macmillan Publishers Ltd: *Nature*, 477, 271–275 (15 September 2011) doi:10.1038/477271a, copyright 2011.

One of the other students in the class, Mary, raised her hand: "I've read that methane in the atmosphere contributes to climate change. Oh, and methane's boiling point is –161 °C (–257.8 °F). But what does that have to do with anything?"

"Well it really is the answer to Steve's question about the water catching on fire," replied Professor Donatello. "You see, when the water and methane are coming out of the faucet, the methane is a gas at room temperature and that gas is what is lit on fire, not the water. Water puts out fires by cutting off the oxygen supply to the fuel that is being burned; but if the fuel is gas, it can escape from the faucet and have plenty of contact with the oxygen in the air."

"I can see that now," interjected Steve, "but I've done a little more research and I've found that methane can be found in well water just naturally. So it seems to me that if you have methane coming out of your faucet maybe it didn't come from hydrofracking."

"That's right," confirmed Professor Donatello. "It's called 'biogenic' methane and as you may guess it is produced by living things—bacteria. Methane that comes from hydrofracking is called 'thermogenic'."

"So how do you know if the methane is coming from bacteria or from hydrofracking?" asked Steve.

"Well," replied Professor Donatello, "chemists can distinguish between the two types using an instrument called a mass spectrometer."

Steve had never heard of it. "How does that work?" he asked.

"Before we can understand how mass spectrometry works and is used to distinguish between the two types of methane, we need to know something about isotopes," said Professor Donatello.

"I know we covered that in high school chemistry, but I've forgotten what that is," Mary said.

"That actually is the next topic we were going to cover," continued Professor Donatello. "We've already learned that an atom contains protons and neutrons located in its center and electrons that are located further away from that center."

"Yes, and only the protons and neutrons contribute to the mass of the atom," said Mary.

"Well, actually the electrons do have mass, but we say that the mass is so small compared to the protons and neutrons that we consider the mass contribution to be negligible," Professor Donatello explained.

"Yes, but what is an isotope?" asked Steve.

"Well, you are going to tell me!" exclaimed Professor Donatello.

Part III – Atoms and Their Isotopes

The students knew what that meant. Professor Donatello was going to put them into small groups to do some guided inquiry learning. Professor Donatello had seen from experience that students seemed to retain information longer when using this type of learning process. Here is the activity she gave them:

Use the following models of two atomic nuclei to answer the questions below:

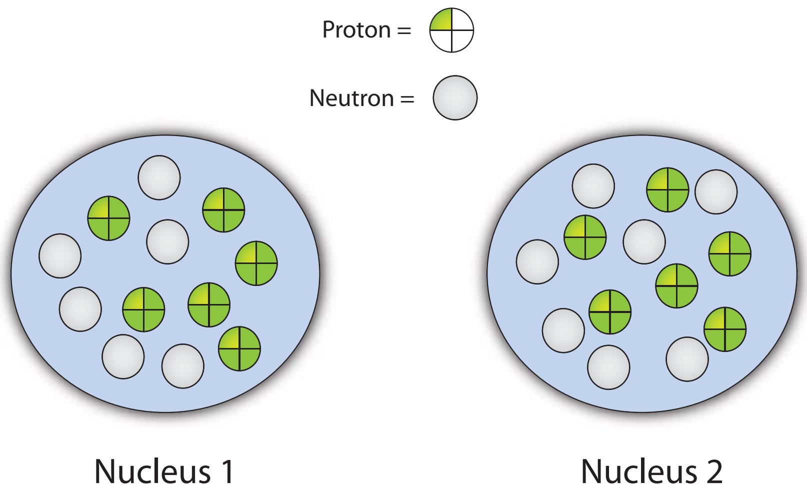

Figure 2. Diagram of Isotopes.

Questions

1. What is the same about the nuclei of these atoms? (Disregard the exact positions of the particles.)
2. What is different?
3. Based on the number of protons, what element are these models depicting?
4. If the mass of a proton is 1 atomic mass unit (amu) and the mass of a neutron is 1 amu, what are the masses of these nuclei?
5. These two atoms are isotopes of one another. Based on the model, give a definition of "isotope."
6. Write a symbol for the two atoms in the form ^{mass}Element. For example, nitrogen with a mass of 14 atomic mass units would be ^{14}N.

Part IV – Mass Spectrometry

Steve was satisfied that he now understood what was meant by "isotope." "But we were talking about methane and hydrofracking," he said with a puzzled look on his face.

Professor Donatello replied: "Yes, you see the ratio of ^{13}C to ^{12}C found in a methane sample from a thermogenic source is different than that found in a biogenic source. We can use a mass spectrometer to determine these ratios."

"So how does that work?" asked Steve.

Professor Donatello referred the students to the schematic of a time-of-flight mass spectrometer, shown below.

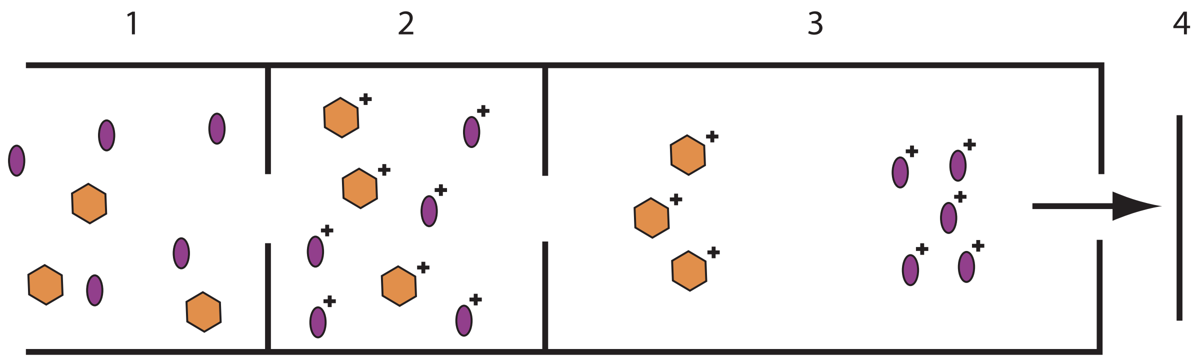

Figure 3. Schematic of a Time-of-Flight Mass Spectrometer.

Professor Donatello continued: "As you can see from the schematic, first the instrument turns the atoms into ions (labeled no. 1 on the schematic). This process is called ionization. Secondly the ions are accelerated toward a detector by applying an electric field (2). The ions will then have the same kinetic energy as they enter the third stage (3), the time-of-flight drift tube. They will drift through the tube to the detector (4), where they will essentially be counted and recorded."

Steve blurted out, "Would the heavier or lighter isotope of carbon get to the detector first?"

Professor Donatello always liked students to answer their own questions, "Well, think about it; if you are running upstairs without books or with books, which takes you longer?"

"Ah, okay," said Steve, "that makes sense. The lighter particle arrives first."

Dr. Donatello nodded her head: "Yes, and that means that the time it takes for them to get to the detector identifies the isotope. The amount of signal produced tells you how much there is of each type. Thermogenic methane will show a higher ratio of ^{13}C."

Dr. Donatello continued: "Here is what typical mass spectra look like. This one is for the molecule toluene. When the peaks form a pattern for a molecule, we call that a fingerprint for that molecule. So spectra identify molecules just like your fingerprint identifies you. Thermogenic methane will have a different pattern compared to biogenic methane."

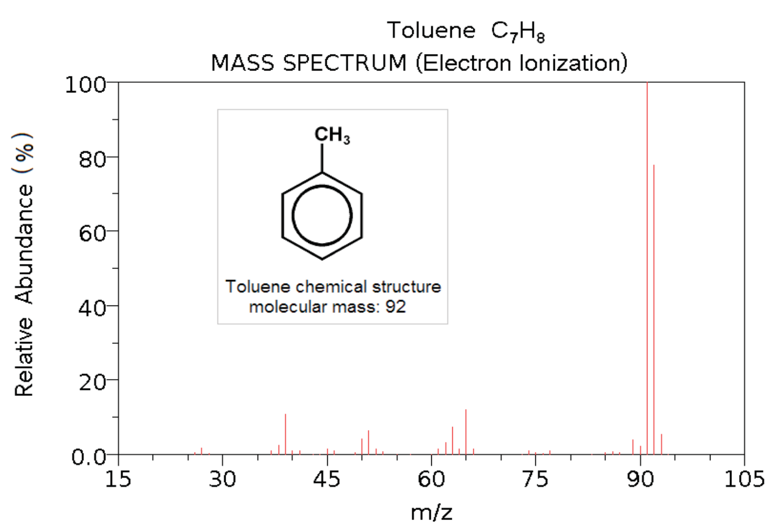

Figure 4. Electron Ionization (EI) Mass Spectrum (MS) of Toluene, C_7H_8.
Source: http://commons.wikimedia.org/wiki/File:Toluene_ei_ms.PNG

Questions

1. What do the lines represent in the spectrum above?
2. What do the lengths of the lines tell you about the atoms?
3. Why would the spectra for thermogenic methane be different than biogenic?

"But I don't have a mass spectrometer," said Steve. "So how would I know if my water is contaminated by hydrofracking?"

"Well," replied Professor Donatello, "since hydraulic fracturing is becoming more popular in the industry, many scientists are investigating the safety of this method. For example, scientists at Duke University looked at some wells in New York State. These wells had methane in them. They did find that the source of methane in these wells seemed to be thermogenic, according to their data."

"So we kind of have to trust other people to monitor things," said Mary.

"This hydrofracking seems like risky business to me!" added Steve.

"There is risk in everything we do," said Professor Donatello. "Of course, more research needs to be done—and if the industry is not as safe as we would like it to be, we have to decide how we can improve safety if we think hydrofracking is worth it. Everyone has to think about how much risk you are willing to accept. How safe something is might be subjective, so societies have to decide what is acceptable. Think about those advantages and disadvantages you researched. Unfortunately science can't always give us all the answers about what we should do. But science can help us find the truth on which to base our decisions."

Optional Questions for Further Investigation and Discussion

1. What are some of the chemicals involved in the hydrofracking process?
2. How could these chemicals be detected?
3. How many confirmed cases of methane well contamination from hydrofracking are there nationwide?
4. Would you be willing to have hydrofracking on your property if you were monetarily compensated?

Recommended Sources of Information for Students

Howarth, R.W., Ingraffea, A., and Engelder, T. 2011. Natural gas: should fracking stop? *Nature* 477: 271–275 [Online] September 15, 2011. http://www.nature.com/nature/journal/v477/n7364/fig_tab/477271a_F1.html.

Soraghan, Mike. 2011. Baffled about fracking? You're not alone. *New York Times*. [Online] May 13, 2011. [Cited: February 10, 2014.] http://www.nytimes.com/gwire/2011/05/13/13greenwire-baffled-about-fracking-youre-not-alone-44383.html?pagewanted=all.

United States Environmental Protection Agency. 2012. Hydraulic fracturing background information. [Online] May 9, 2012. [Cited: February 13, 2014.] http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_hydrowhat.cfm.