MaD Science – Rocket Fuel

Rocket fuel is one of the most dangerous, most explosive, yet most fun materials we can make. We need to be extra careful to get the mix just right! Can you make some precision chemical rocket fuel?

DANGERS!

This section cannot explain every possible danger in this activity. Adult care and surveillance is required at all times. Please exercise all appropriate caution at all times.

Caustic soda can cause sever eye damage. Wear goggles and gloves at all times. Have an eye wash on hand at all times. DO NOT touch the chemicals before, during or after the experiment. Dispose of down a sink.

DO NOT put your naked eyes over the caustic soda when it's reacting with the aluminium – it will sting and potentially damage you.

This reaction is **exothermic** – it can burn you. Have water on hand.

Setting **fire** to hydrogen gas causes a small explosion. This can set fire to surrounding materials, such as balloons and wick strings. There will be fire, please prepare appropriately!!!

If you put a lid on the bottle while it is building up the hydrogen gas, it can create a high pressure **explosive**. DO NOT put a lid on the bottle at any time.

You are making **hydrogen gas**. It loves to explode in a ball of fire. This fire will set fire to flammable things such as hair, loose clothing, or nearby decorations. Due to wind, this activity usually needs to happen in shelter or indoors. Ensure a *minimum 5 meter clearance* at all times. Be careful.

Hydrogen is less dense than surrounding air – it will float up and away if you give it that chance. If there is a spark before it's had time to dissipate (usually a few meters), it may burst into flames. Hydrogen balloons will float away if you let them, be careful.

Suggested Outcomes

(NOTE: This is by no means an exhaustive list of possible outcomes, neither is it intended that ONLY these outcomes can or should be met. Science is a deeply interrelated activity, and you may find cross curriculum links you can and should use.)

Science content

- Chemical sciences 6: Changes to materials can be reversible or irreversible (ACSSU095)

- Chemical sciences 7: Mixtures, including solutions, contain a combination of pure substances that can be separated using a range of techniques (ACSSU113)

Science inquiry skills

- Planning and conducting 6: Identify, plan and apply the elements of scientific investigations to answer questions and solve problems using equipment and materials safely and identifying potential risks (ACSIS103)

- Evaluating 7: Reflect on scientific investigations including evaluating the quality of the data collected, and identifying improvements (ACSIS131)

Science as a human endeavour

- Use and influence of science 6: Scientific knowledge is used to solve problems and inform personal and community decisions (ACSHE100)

Cross curricular outcomes

- Design and Technologies Knowledge and Understanding 5 & 6 - Investigate characteristics and properties of a range of materials, systems, components, tools and equipment and evaluate the impact of their use (ACTDEK023)

- Design and Technologies Processes and Production Skills 5 & 6 - Select appropriate materials, components, tools, equipment and techniques and apply safe procedures to make designed solutions (ACTDEP026)

- Design and Technologies Knowledge and Understanding 9 & 10 - Investigate and make judgments on how the characteristics and properties of materials are combined with force, motion and energy to create engineered solutions (ACTDEK043)

Science vocabulary words

Tier 1 (Everyday words) Rocket, fuel.

Tier 2 (Dual meaning)

- Inflammable. Technically, inflammable means 'able to burst into flames', but since the word 'flammable' also means this, the word 'Inflammable' is sometimes mistaken as flammable's antonym, which it is not. The antonym of inflammable is 'non-flammable'

Tier 3 (Specialised vocabulary)

- Hydrogen – the smallest atom we know about, it can form a gas as two hydrogen atoms grab a hold of each other. This gas combines easily with oxygen and explodes.
- Oxygen – an atom that easily recombines with other atoms, it can form a gas as two oxygen atoms grab a hold of each other. We, and almost all living creatures, need oxygen to survive.
- Deflagration – a kind of slower-than-sound explosion where a material is set on fire by the heat produced by other parts of that material heating up.
- Exothermic – a chemical reaction that releases more heat than it consumes. Some reactions are so exothermic they can create glowing, super-hot air, AKA "Explosions".

Preparation

Parents – if you are able to bring along any sensitive scales you might have (i.e., able to measure in grams) it would be deeply appreciated and very helpful.

For safety, please remember:

- Hair and loose clothing tied back.
- DO NOT perform this activity near inflammable materials, such as curtains or hair.
- We recommend gloves, goggles, and lab coats as a bare minimum safety standard.
- Have water and fire extinguishers on hand at all times.

You will need the following materials to make hydrogen gas:

- About 500grams of sodium hydroxide, usually sold as 'caustic soda', and usually available in supermarkets. DO NOT get the drain cleaner with aluminium pieces already visible within – it will work way too fast for our needs today.
- Aluminium foil, again ready available at most supermarkets. Half a meter per child is usually more than sufficient
- Plastic bottles – lids THROWN AWAY, labels removed.
- Buckets of water on hand, for scorched fingers or in case something catches on fire. If you have at least 1 clear bucket it can help you to see the reaction in action.
- Balloons, good, strong helium latex balloons are recommended.

And to set fire to the hydrogen gas you'll need.

- An indoor area free from wind and flammable materials, and far away from any working fire alarms. (We're making water so there's much less chance of them going off, however)

Or

- A safe, large outdoor area – free from dry grass or flammable leaves such as eucalyptus.
- A place to set the fire – metal lined tables or concrete floors are recommended.
- A wick: 2m of thick, absorbent string. Twine is usually best. (If you want to have a shorter wick, use 1m of string tied to a metal nut or bolt.)
- Accelerant for the wick – methylated spirits is recommended. (Petrol is disastrous – DO NOT USE PETROL!!!!).
- Something to start a fire, a BBQ firelighter is usually sufficient.

Learning Intent (student friendly)

'We are learning to' (WALT) safely and effectively create and set fire to hydrogen gas.

Success criteria

'What I'm looking for' (WILF) correct calculations of reagents, safe handling of reagents, a clear and effective presentation on safety protocols, and a small ball of fire.

Student learning goals

Help students make a self-monitored learning goal for this lesson, such as 'safely make a ball of hot, glowing, steam.'

Evidence of learning

How will you know when the learning goal is achieved? What EVIDENCE do you have that your students have met or exceeded the learning expectations?

- They present a page outlining either/all;
    - A page describing the chemical reaction
    - The mathematical calculations of reagent masses
    - A safety poster regarding 'making rocket fuel'

Suggestions for other year levels

As always, more material is presented here than can be used by the average class during the average lesson time. However, since the students questions can and should guide student learning, more material is presented for you convenience. Remember, it is not uncommon for students to only remember those points which answered their personal questions.

Younger:

This activity is intended as a demonstration for young people. Only under the most carefully managed situations should young children be allowed near caustic soda or gaseous hydrogen. Keep the chemicals out of reach at all times during storage. USE GLOVES AND GOGGLES!!!

The reaction is *very hot*, and must be carefully policed.

The fireball can set fire to light, flammable objects immediately. Be sure all light clothing and children's hair are kept well back from the event.

Middle:

This activity is well suited to this age group if managed properly. Be sure to instruct students on all dangers and danger management protocols.

Teen:

Arguably, the greatest danger in this activity is that you are teaching a young teenage how to create a bomb. Counterpoint; all this information, and much worse, is freely available online. It is much safer to teach it here, where adequate safety standards can be promoted and encouraged.

Science involves doing dangerous things properly; that is the nature of it. Without rocket science, we could not get satellites into orbit, make planes that cross the world in only two hours, or make rockets that get people onto the moon.

Having said, it is wise to discourage discussion on how to damage property or other people.

Engage

If you have time, you might like the share the following video of a fire at a rocket fuel manufacturing plant - https://www.youtube.com/watch?v=_KuGizBjDXo

- ⇨ Note the Learning Intention of this lesson for students.
- ⇨ Make sure all students write down any questions they may have generated during this phase regarding the topic for today.

Demonstrate the creation of rocket fuel. You may wish to use the following story to help illustrate the importance and history of rocket fuel.

"This next reaction takes a little time to get going, but that's good. This reaction gets hot, really hot. And as it gets hotter, it gets faster. So we might need to cool it down in this water here. It should take about 5 minutes, and that gives us a chance to chat… Did you know that at the end of World War 2 the Axis scientists invented rockets that could go from one country right to another country. It was terrifying!! A rocket could come out of nowhere, anytime, and blow an entire building up. So when the Allies beat up on the Axis they captured their rocket scientists as said, 'instead of using your rockets to blow people up, let's use them to help us get to the moon!' and so the deadly rocket science turned into the helpful science of space exploration!"[1]

Ignite the rocket fuel.

Explore

⇨ Encourage and validate student explanations of this phenomenon. You may like to ask students to write or draw their explanation personally to avoid embarrassment to students unfamiliar with this material. Remember, 'I don't know' is a valid explanation in science – it is the beginning of learning new things!

Tell students: rocket fuel is an incredibly dangerous chemical, and we made less than a teaspoon of it! If you want to make some rocket fuel, we're going to have to be very careful scientists!

⇨ Make some rocket fuel from the appendixes. Feel free to use extra activities such as 'finding the volume of a sphere' and 'calculating the exact amount of reactants we'll need'.

Explain

The chemical equation for making hydrogen is;

$$2\ Al + 2\ NaOH + 2\ H_2O \rightarrow 2\ NaAlO_2 + 3\ H_2$$

Meaning two atoms of aluminium mixed with two molecules of sodium hydroxide and two molecules of water to make one molecule of sodium aluminate and 3 molecules of hydrogen gas.

Calculate:

How much of each reactant do we need? See the appendix for exact calculations. Bu to be brienf, if we want 4 litres of H_2 gas, we need:

- aluminium = 3.24 grams
- sodium hydroxide = 4.8 grams
- water = 2.16 grams

To create

- sodium aluminate = 9.84 grams
- hydrogen gas = 0.36 grams

---

[1] The recount here is very, very brief. Older groups might have something to add to this story, or enjoy learning about some of the important people involved such as Wernher Von Braun, Helmut Gröttrup. This story is also ignoring how much rocket science went into the next decade of nuclear build-up world wide, but that's a story for another time.

The chemical story (optional)

One day, the "sodium hydroxide" friends were hanging out. They had:

An oxygen atom, with 2 empty slots for electrons,

A sodium atom, who has one electron to hand around,

And a hydrogen atom, who also has one electron to hand around,

Meaning oxygen sat in the middle holding on to hydrogen and sodium, and all was well.

And …

Just next to them sat the 'water' friends.

Again, an oxygen atom, with 2 empty slots for electrons,

And two hydrogen atoms, who also has one electron to hand around,

Meaning oxygen sat in the middle holding on to two hydrogens, and they were happy.

Then…

Along came Aluminium…

Aluminium has three spare electrons. Aluminium was hanging around with all the other aluminium buddies – there were billions of them. But, tempted by the energy of the water, one aluminium strolled over.

Everything gets really weird around then.

So the aluminium immediately attracts both oxygen atoms, holding onto one a little tighter than the other. The sodium has trouble letting go of the less tightly bonded oxygen atom and keeps hanging around like the 4^{th} wheel in a three way love triangle.

The spare hydrogens, with nothing to do, eventually grab hold of each other and they run away together.

Elaborate

- ⇨ Ask students if they can design new ways to test this explanation, is it really sufficient? Can they think of further or better explanations, and the experiments needed to test them?

Making water

So what is the chemical equation for exploding hydrogen? Pretty simple;

$$O_2 + 2H_2 \rightarrow 2\ H_2O$$

Or one molecule of oxygen, plus two molecules of hydrogen gas, will equal two molecules of water. Of course, this reaction realises a LOT of energy, meaning our water will not only evaporate and turn into steam, it also heats the nearby air up so much that it glows – i.e., it makes fire.

How much fuel do rockets need?

By weight, rockets are around 90% propellant and only 10% mass, meaning the entire rocket and all its occupants weigh only 1/10th of the weight of the entire rocket once the fuel is added. Rockets have a LOT of fuel to get into orbit.

Ever wonder why the explosions when the rockets hit the ground are so dramatic?

So how much fuel is that? The American space shuttle, one of the heaviest space ships so far, required around 1,687,363 kilograms of fuel (1600 tonnes – about the same as 1000 average cars!!!). And the space X rocket will need about $300,000 of fuel just for a single trip!

Can you find out how much rocket fuel it would cost to send just you in a 100kg spacesuit into space?

What do we need to make rocket fuel?

What is rocket fuel make from?

Imagine you are a deep solar system explorer. We've got a good enough space ship and enough rocket fuel to send you anywhere in the solar system, but once you're there you'll have to find a way to make your own rocket fuel to get back.

Where would you go, and what would you need to make your own rocket fuel once you got there?

Other uses for this reaction?

The reaction of using hydrogen and oxygen to make water has very few pollutants – water is quite useful. Can you research other uses of hydrogen gas? What is needed, and what are the problems?

Scientists have tried to develop cars that run on water, by splitting the hydrogen and oxygen into tanks and then carefully exploding them together in the engine. However, hydrogen gas is a LOT more explosive than petrol, so in an accident a petrol car might burst into flames, a water powered car might explode in a devastating fireball capable of taking out an entire building. What do you think? Is this a technology we should explore further? What solutions have they found already that can make the dream of a water powered car a reality?

Evaluate

⇨ Review with students what they felt they learnt from this lesson. Did they have any questions at the start that they feel were answered?

Success criteria

⇨ Review the Learning Intentions of this lesson with students. Was it met?

At the end of each class, review the learning objective and see how we did. Ask:

⇨ Did you achieve your learning goal?

⇨ What did You learn?

⇨ What worked to help you achieve it?

⇨ What might you do better next time?

⇨ (If needed) where can you go for extra help or information?

Assessment

Prior learning:

Find out what students already know about rocket fuel. Are there different kinds? What else can we use it for? What do we need to make rocket fuel?

Test students for safety, see if they know why we wear lab coats, goggles and gloves.

Focus on the outcomes – how can we create the BEST scientific knowledge?

Be sure to watch out for the following common alternative conceptions:

- That just because our rocket fuel is a gas, it isn't dangerous. IT IS! In real rockets they compress the gas into a liquid or solid in order to make it safer and take up less space, but it's still rocket fuel!

- Hot things glow. Indeed, hot things often do, but sometimes they glow in colours our eyes cannot see, such as infrared (black car seats) or ultraviolent (i.e., aluminium). Be very careful around potentially very hot things.

Formative:

As students are learning, help them self-monitor their own learning and achievements.

Be sure to monitor safety behaviours. Ask students

1. What do we need to do in order to stay safe in this situation?
2. WHY do we need to do those things/ How do they actually help?
3. What would you say to a much younger student about that safety rule?

Summative:

Help students consider ways they can communicate their new understanding to others, just as scientists need to do. They may present a document outlining either/all;

- A page describing the chemical reaction
- The mathematical calculations of reagent masses
- A safety poster regarding 'making rocket fuel'

Older groups might enjoy the challenge: Imagine you are a deep solar system explorer. We've got a good enough space ship and enough rocket fuel to send you anywhere in the solar system, but once you're there you'll have to find a way to make your own rocket fuel to get back. Where would you go, and what would you need to make your own rocket fuel once you got there?

Also, scientists have developed cars that run on water, by splitting the hydrogen and oxygen into tanks and then carefully combining them together in the engine. However, hydrogen gas is a LOT more explosive than petrol, so in an accident a petrol car might burst into flames, a water powered car might explode in a devastating fireball capable of taking out an entire building. What do you think? Is this a technology we should explore further? What solutions have they found already that can make the dream of a water powered car a reality?

So what?

Fire and explosions are FUN – managed safely and used appropriately.

Explosions are useful – they can get us into orbit and beyond!

Creating science

Science content

- As we made hydrogen gas rocket fuel, and set fire to it, we saw that chemical sciences 6: Changes to materials can be reversible or irreversible (ACSSU095), and that chemical sciences 7: Mixtures, including solutions, contain a combination of pure substances that can be separated using a range of techniques (ACSSU113)

Science inquiry skills

- In adhering to safety cautions, we were planning and conducting 6: Identify, plan and apply the elements of scientific investigations to answer questions and solve problems using equipment and materials safely and identifying potential risks (ACSIS103)
- In reviewing our experiment we, were evaluating 7: Reflect on scientific investigations including evaluating the quality of the data collected, and identifying improvements (ACSIS131)

Science as a human endeavour

- As we learnt about rocket fuel history and uses, including world war two and space exploration, we had the change to explore the use and influence of science 6: Scientific knowledge is used to solve problems and inform personal and community decisions (ACSHE100)

Cross curricular outcomes

As we made and explored the uses of rocket fuel we gained the chance to;

- Design and Technologies Knowledge and Understanding 5 & 6 - Investigate characteristics and properties of a range of materials, systems, components, tools and equipment and evaluate the impact of their use (ACTDEK023)

- Design and Technologies Processes and Production Skills 5 & 6 - Select appropriate materials, components, tools, equipment and techniques and apply safe procedures to make designed solutions (ACTDEP026)

- Design and Technologies Knowledge and Understanding 9 & 10 - Investigate and make judgments on how the characteristics and properties of materials are combined with force, motion and energy to create engineered solutions (ACTDEK043)

Tips from the Masters to make it work:

1. BE CAREFUL! Goggles, gloves, covered shoes, lab coats etc.

2. Once your sodium hydroxide is in with aluminium, as soon as you add a little water, OFF IT GOES! So make sure your bottle is dry, and do not put the water in using a cup – use a balloon and tip it in gently.

3. DO NOT put a lid on the bottle. It turns into a bomb.

Some other pics from the masters to inspire you – crucifix not required!

Appendix 1: Find the volume of a balloon

- ⇨ Measure the diameter of your balloon – good luck, it's tricky!
- ⇨ Halve that answer to get the radius of your balloon.
- ⇨ Use the equation

$$V = 4/3\pi r^3$$

V = the volume we need to know.

r = the radius of the balloon in centimetres

π = Pi – the ratio of the diameter to the circumference of its circle, cubed to represent length, height and width

4/3 = four divided by three – the ratio of the volume of a sphere inside a cube of the same width. Thank Archimedes (who was so proud of that fact, he had it engraved on his tombstone!)

- ⇨ The result is your answer in cm^3, which, when divided by 1000, give you your answer in litres.
- ⇨ What to check your results? You can shove your balloon inside a bucket full to the brim with water, and measure how much water falls out. The results should be almost the same (accounting for the volume of your hands, - compression of air in water, etc, etc!)

Therefore.

If you balloon is 20 centimetres wide, the radius is 10.

$= 4 \div 3 \times \pi \times 10^3$

Remember, mathematicians, indices come before the × and ÷ , so you can almost do this equation from back to front! $10^3 = 10 \times 10 \times 10 \times$ or 1000

$= 4 \div 3 \times \pi \times 1000$

= 4,188.79 OR 4.18 litres!

What if your balloon was 2 cm wide? Or 200?

Appendix 2: How many atoms do we need?

So how many atoms of hydrogen do we need to fill our balloon?

The number of atoms in 1 mol of hydrogen would be 12.04×10^23 atoms (since, in the air, hydrogen forms into pairs, making a hydrogen molecule of 2 atoms each).

1 mole of hydrogen fills approximately 22.4L of volume.

= 22.4 litres in one mol ÷ 4.18 litres in our balloon

= 5.36, meaning our balloon is 5.36 times smaller than 1 mol of hydrogen

Or in other words, we need 1 ÷ 5.36, or 0.18 a mol of hydrogen

Incidentally, we'll also need to know that;

1 mol of hydgrogen = 2 grams

1 mol of aluminium = 27 grams

1 mol of sodium hydroxide = 40 grams

1 mol of water = 18 grams

How many grams of each reactant do we need?

$$2\ Al + 2\ NaOH + 2\ H_2O \rightarrow 2\ NaAlO_2 + 3\ H2$$

Or 2 atoms of aluminium will mix with 2 molecules of sodium hydroxide (caustic soda) and 2 molecules of water...

...to produce 2 molecules of sodium aluminate and 3 atoms of hydrogen

Or in other words, 2 moles of Al plus 2 of NaOH plus 2 of water make 2 of sodium aluminate and 3 moles of hydrogen gas.

As we do not need 3 moles but 0.18 moles (see the maths above) then divide the quantities in the equation by 3 and multiply by 0.18. This then reduces the moles to the correct quantities.

To make .18 mol of hydrogen, we will need:

2 / 3 x 0.18 = 0.12 mol of aluminium or = 27*.12 = 3.24 grams

2 / 3 x 0.18 = 0.12 mol of sodium hydroxide = 40 x .12 = 4.8 grams (as soon as you add this the reaction will start… but it won't get going until you add

2 / 3 x 0.18 = 0.12 mol of water = 18 x .12 = 2.16 grams (put in balloon and tip into bottle)

for a total mass of 10.2 grams

incidentally, this will make;

2/3*.18 = 0.12 grams of sodium aluminate (MW = 82) = 82 * .12 = 9.84 grams

and 3/3*.18 = .18 hydrogen gas (MW=2) = 2 *.18 = 0.36 grams

For a total mass of 10.2 grams, so we know our maths is correct!

We used:

aluminium or = 3.24 grams

sodium hydroxide = 4.8 grams

water = 2.16 grams

To make:

sodium aluminate = 9.84 grams

hydrogen gas = 0.36 grams

Scientist's name:

Date:

Making rocket fuel

1. Measure out ____ grams of water. Add about 3ml more water to account for drips that will get stuck on your balloon and bottle and not get into the mix. Place all the water into a balloon. **Too much water (i.e., a balloon full, will accelerate the creation of hydrogen, potentially melting your bottle or bursting your balloon with the expanded hot gas.)**

2. Measure out ___ grams of aluminium. If you like, roll it into tiny balls to help increase the surface area while decreasing overall volume (so it all fits in the bottom CM of your bottle). Place your aluminium bits into the plastic bottle. **Make sure your bottle is dry and free from water drips or soft drink or the reaction make happen too soon!**

3. **Wear gloves and goggles, these next steps can irritate skin and damage eyes!!!** Measure out ____ grams of sodium hydroxide and place them into your dry plastic bottle. **Be careful!**

4. Place your plastic bottle into some water to help cool down and thus slow down any chemical reactions. Place your balloon over your bottle and carefully tip the water in a few drips at a time. Observe and record reactions carefully. **Beware! This reaction is EXOTHERMIC – meaning it can get HOT!! DO NOT touch the bottom of the bottle, and keep the bottle in the water to help slow down the reaction** (see 'tips from the masters'.)

5. The hydrogen gas will initially be very hot, dramatically increasing its volume, **you need to wait at least 5 minutes for it to cool back down to room temperature**, which helps to give all the chemicals a chance to fully react. Can you see the steam condensing on the inside of the balloon – **BE CAREFUL! YOUR BALLOON IS NOW FULL OF ROCKET FUEL – IF YOU PUT A FIRE NEAR IT NOW IT WILL EXPLODE IN A BALL OF FLAMES!**

Ignition options:

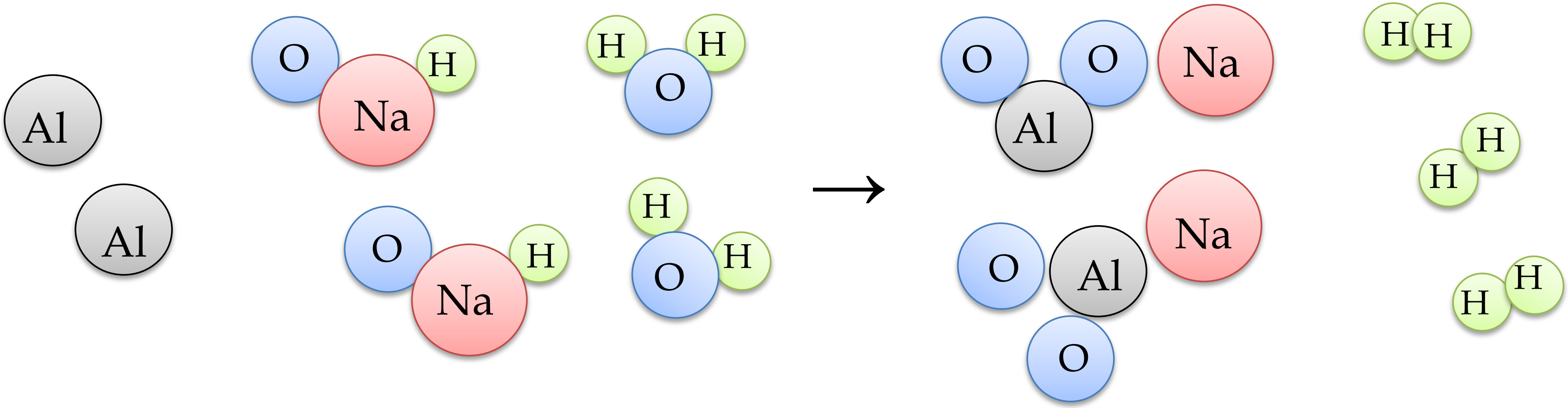
A. Direct ignition (possible inside option): After the chemicals have stopped reacting, keep the balloon *on the bottle* and set fire to it using a long BBQ lighter – **but be sure you're wearing, gloves, goggles and safe clothes such as a lab coat.** NOTE the balloon bits on the bottle may catch on fire, so be sure to have a wet cloth on hand to smother any flames. **Be very careful of setting off fire alarms –** while the only reactant of the hydrogen gas is water (which is not expected to set of standard fire alarms), burning balloons are not.

B. Light the fuse (best as an outside option – but it does leave burning bits of string and balloon around). **Designate a safe area for the ignition, such as where observers are at least 5 meters away behind a fence.** Make sure there is no dangerous breeze. Under cover areas that are a little darker are a good choice. Tie a piece of yarn to the balloon, about 2 meters, with a heavy metal nut on the end to prevent the balloon flying around. Soak the yarn in metho to make it a 'fuse'. Stand back. Light the fuse and GET BACK! Burning balloon and yarn shrapnel will fly up to 2 meters in a random direction, be sure no flammable materials are within 5 meters. Have wet rags and other extinguishing gear on hand to extinguish the flames. You could do the fuse reaction inside but will need at least 10 meter clearance from students, as burning string does go flying.

6. Please note – burning balloon bits are STICKY and can get into skin and clothes. Once denatured, burnt balloons require metho to clean them off.

Making rocket fuel

$$2\,Al + 2\,NaOH + 2\,H_2O \rightarrow 2\,NaAlO_2 + 3\,H_2$$



1 mol of hydrogen is around 12.04×10^23 atoms, around 22.4L in volume, about 2 grams.

1 mol of aluminium = 27 grams

1 mol of sodium hydroxide = 40 grams

1 mol of water = 18 grams