Teacher Notes

Shooting – exothermic reactions and the fire triangle

Sport: Shooting

Age group: 14 – 16

These notes are designed as a guide on to how to lead the session, and are written in a script format. If you wish to lead the session in a different way, please feel free to do so.

The **red text** indicates what each slide includes, while the **blue text** highlights the key points being discussed in each slide where appropriate. The **owl symbol** demonstrates where students are required to perform a task (eg questions, experiment, etc.). These are used to help you observe the students learning and recap any information which the students have found difficult to understand.

Opening slide introducing the module.

Slide 1 – Shooting – exothermic reactions and the fire triangle

The first slide provides the title of the session introducing the sport and science area covered in the module.

Slides 2 & 3 – Shooting and the link to chemistry

Shooting, although now a sport, was born out of an activity that was not created for recreational purposes. The activity itself was developed for two primary reasons. The first was to provide a mechanism to aid hunting and thus the provision of food and the second was as an offensive and defensive weapon to increase a society's chance of survival.

Slide 2 – an introduction to shooting and a brief history.

Fact
Bisley is the centre for shooting in Great Britain and has World renowned facilities.

The National Rifle Association (NRA) is now the governing body of full-bore rifle and centre-fire pistol shooting in Great Britain and although other governing bodies regulate certain specific types and disciplines of shooting the NRA is probably the most well known and over arching body of its kind. It was founded in 1859, originally to provide a focus for marksmanship for the newly formed corps of volunteers from Great Britain which had been raised to meet the perceived threat of invasion by the French.

Bisley became the home of the NRA in 1890 and Queen Alexandra fired the first shot at the beginning of the Imperial Meeting that year. The Bisley land costs over £13,000 and almost exhausted the reserves but the War Office provided working parties from Aldershot to level the ranges and construct the butts.

Bisley is now World renowned as a shooting venue and boasts the unique combination of the best, most modern, and largest arrangement of shooting facilities in the world combined with its beautiful colonial-style clubhouses.

Bisley houses the National Shooting Centre and hosts many events every year including the National Championships for a range of different disciplines of both Rifle and Pistol types. It has most recently hosted all the shooting events for the 2002 Commonwealth Games and will be hosting a number of events at the 2012 Olympics.

Slide 3 – the link between shooting and chemistry.

Key Point
All methods used to propel a bullet from a gun barrel rely on the transference of energy and are based on scientific principles. Some methods such as the ignition of gunpowder rely on kinetic energy being transferred to a bullet from energy produced in a chemical reaction.

Over many centuries shooting and the equipment, or guns used, have been refined to be more affective. As technology and science's understanding has developed so has the equipment used for shooting. In today's world guns work through a variety of different mechanisms, which include physical properties such as spring loaded guns using the property of stored kinetic energy in a spring to propel the bullet forward. Air guns force air into a chamber which then, due to a huge increase in pressure within that chamber propels a bullet out of the other end. Finally chemical reactions are also used to propel bullets from a gun. The most well known example of this is the ignition of gunpowder.

The link between shooting and chemistry is really in the chemical reaction that takes place when gunpowder ignites producing the energy needed to propel a bullet out of a gun. However before we explore gunpowder in more detail it is worth reminding ourselves of the fire triangle and combustion reactions.

Slides 4 & 5 – The fire triangle

A recap of the fire triangle.

Key Point
In order for a fire to take place three inter-related components must be present. They are a fuel source, a source of energy, and something which will ignite the fire (a spark or flame normally).

You may remember that the fire triangle is an inter-related set of three requirements for a fire to take place.

First there must be a source of fuel to burn – this will most commonly contain carbon. Second there must be oxygen present to allow the fuel to burn and for the carbon in the fuel to react with the oxygen, normally forming carbon dioxide, although other compounds including carbon monoxide are often also formed. Finally there must be a heat source or ignition source which starts the reaction off. This is commonly a flame or a spark but it can be caused by electrical energy, amongst other things.

The energy which is given off, once the fuel has started to burn, then supplies the heat source or ignition source needed for continued reaction. The fire will only go out once either the oxygen supply or fuel supply is removed. Fire is an example of a combustion reaction.

Slide 6 – Combustion reactions

Slide 6 examines combustion reactions giving some common examples.

Combustion reactions are reactions with oxygen which are normally accompanied by a release of energy. Typically heat energy and light energy are produced when a combustion reaction is taking place. When something is on fire we normally associate that with heat and light being produced and fire is the most widely recognised visual example of a combustion reaction taking place. A coal or log fire is a great example of this where one can feel the heat and see the flames of the fire. Many of the combustion reactions we come across in our daily lives are as a result of a fuel being burnt in oxygen. Carbon is often present in the fuel and is normally what is being burnt in the combustion reactions we encounter. In our earlier examples of a log or coal fire both the logs and coal have an extremely high percentage content of carbon. It is the carbon which is present in gunpowder which is the main fuel source of the combustion reaction which takes place, ultimately resulting in a bullet being propelled out of the gun barrel.

Slide 7 introduces traditional gunpowder and its components.

Key Point
Modern day gunpowder is different to traditional gunpowder but both are a mix of chemicals which result in a combustion reaction taking place when they are ignited.

Slide 8 explores the composition of gunpowder and looks at the percentage by weight of its common components.

Key Point
Nitrate, commonly potassium nitrate, is often considered the most important component of gunpowder as it is this component which supplies the oxygen for the combustion reaction to take place.

Slide 9 gives two simplified chemical equations for the combustion of traditional gunpowder.

Slides 7 - 9 – Traditional gunpowder

Gunpowder, also known as black powder, is a granular mixture of charcoal, sulfur and potassium nitrate, KNO_3 (which is also known as saltpetre). The mixture, when ignited, is explosive and burns rapidly producing volumes of gases and hot solids which can be used as a propellant in firearms. Traditional black powder, or gunpowder, as just described is now rarely used in firearms, other than when using traditional or antique guns, and has been replaced by a smokeless powder. However, for the purpose of this module, when we refer to gunpowder it will be with the traditional mixture of components.

Gunpowder, as we have learned is a mixture of a nitrate, charcoal and sulfur. The current standard composition of the mixture was developed as long ago as 1780. The proportions by weight of the mixture are changed slightly depending on the purpose of the powder but normally roughly 75% potassium nitrate, 15% charcoal (normally from a soft wood), and 10% sulfur. Each of the components in the mixture have a specific purpose in the reaction, these purposes are as follows:

- The nitrate, typically potassium nitrate, supplies the oxygen for the reactions which take place when the powder is ignited.
- The charcoal provides carbon and other fuel sources for the reaction.
- The sulfur lowers the temperature of ignition and increases the speed of combustion whilst also acting as an additional fuel source.

The potassium nitrate is probably the most important of the ingredients because during the combustion process it releases oxygen promoting the rapid burning of the other ingredients. The reactions that take place are extremely complicated and difficult to represent as a very wide range of compounds have been found to have been formed when reacted gunpowder has been analysed by chemists.

However a simple chemical equation, which is commonly used, representing the combustion of gunpowder is as follows:

$$2KNO_3(s) + S(s) + 3C\,(s) \longrightarrow K_2S\,(s) + N_2\,(g) + 3CO_2\,(g)$$

A still simplified equation that represents the reaction slightly more accurately is:

$$10KNO_3(s) + 3S(s) + 8C(s) \longrightarrow 2K_2CO_3(s) + 3K_2SO_4(s) + 6CO_2(g) + 5N_2(g)$$

An introduction to exothermic and endothermic reactions.

Key Point
In an exothermic reaction more energy is produced from the reaction than is needed to initiate it.

Key Point
In an endothermic reaction more energy is needed for the reaction to take place than is produced.

Slide 10 – Exothermic and endothermic reactions

When gunpowder is ignited chemists might refer to the reaction as being exothermic. An exothermic reaction is a chemical reaction which produces energy, normally given off in the form of heat. Combustion reactions are great examples of exothermic reactions.

The chemical equation for an exothermic reaction can be represented as follows:

$$\text{Reactants} \longrightarrow \text{products + energy}$$

All reactions require energy to initiate the reaction. In an exothermic reaction the energy produced by the reaction far outweighs the energy needed to initiate the reaction.

\`\n endothermic reaction requires more energy for the reaction to be completed than the ımount of energy which is produced. This can be represented as follows:

$$\text{Reactants + energy} \longrightarrow \text{products}$$

Slide 11 introduces the topic of enthalpy change, ΔH before slides 12 & 13 give examples of energy diagrams for an exothermic reaction, slide 12 and an endothermic reaction, slide 13.

Key Point
ΔH = energy used in bond reactions – energy released in bond making reactions. By definition enthalpy change, ΔH, has a negative or minus value.

Slide 11 - 13 – Enthalpy change, ΔH

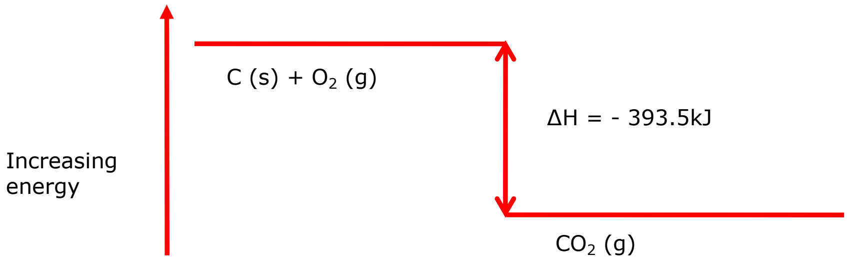
It is very difficult to measure the absolute amount of energy in a chemical system. Chemists therefore measure the enthalpy change, ΔH, of a chemical reaction to show if it is exothermic, or endothermic. The enthalpy change, ΔH value, is related to energy needed to make and break bonds during a chemical reaction. Chemists can work out the ΔH value of a reaction using the following equation:

ΔH = energy used in bond breaking reactions – energy released in bond making products.

By definition the enthalpy change has a negative or minus value: $\Delta H < 0$. Therefore for an exothermic reaction a negative ΔH is produced, as a larger value (the energy released in the reaction) is subtracted from a smaller value (the energy used for the reaction). In an endothermic reaction ΔH is positive; more energy is required for the reaction to take place than is created.

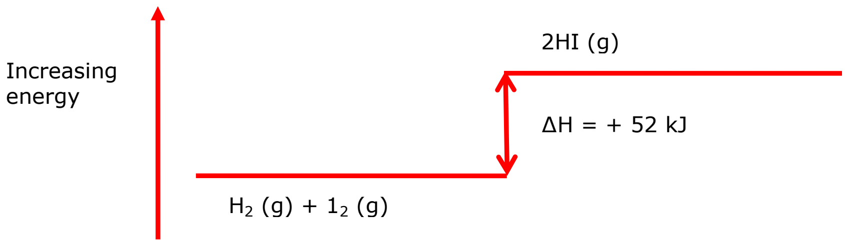
Energy diagrams are often used to express exothermic and endothermic reactions. The following two diagrams are examples of energy diagrams, one for the exothermic reaction of the burning of carbon the other the endothermic reaction for the formation of hydrogen iodide.

Energy diagram for the complete combustion of carbon:



The information above tells a chemist that burning 12 g of carbon in oxygen produces 393.5 kJ.

Energy diagram for the formation of hydrogen iodide:



The information in this energy diagram tells a chemist that a net value of +52 kJ of energy is required for the reaction to take place. As the ∆H is positive the reaction is endothermic.

Slides 14 & 15 – Working out ∆H for a reaction from data tables

Slides 14 & 15 use the example of the formation of hydrogen chloride from reacting hydrogen and chlorine together to show how information from data tables can be used to show if a reaction is exothermic or endothermic.

As we have learned looking at exothermic and endothermic reactions, energy is needed to break bonds and energy is produced when bonds are made. Using data tables, Chemists can work out if a reaction will be exothermic or endothermic. Here is an example using the formation of hydrogen chloride from reacting hydrogen and chlorine together.

$$H_2(g) + Cl_2(g) \longrightarrow 2\,HCl(g)$$

Using relative atomic masses, 2 g of hydrogen react with 71 g of chlorine to form 73 g of hydrogen chloride.

The data book states that it requires +436 kJ of energy to break the H-H bonds in 2 g of hydrogen molecules and +242 kJ of energy to break the Cl-Cl bonds in 71 g of chlorine molecules. The data book also tells us that −431 kJ of energy is released when 36.5 g of hydrogen chloride is formed. As we form 2HCl from 2 g of H_2 and 71 g of Cl_2 then 73 g of HCl are formed.

If it takes −431 kJ per 36.5 g of HCl produced then the energy required to produce 2HCl is twice as much, or −862 kJ.

The energy change is therefore:

+436 kJ (energy required to break H-H bonds in 2 g of hydrogen molecules) + +242 kJ (energy required to break Cl-Cl bonds in 2 g of chlorine molecules) + −862 kJ (energy released in the formation of 2 g of HCl) = −184 kJ.

Or: (+436 kJ) + (+242 kJ) + (−862 kJ) = −184 kJ

As the ΔH for the total reaction is negative then the reaction is exothermic.

The combustion of gunpowder, as we explored earlier is exothermic. That means that more energy is produced in the reaction than is required for the reaction to take place.

Distribute the 'student handout worksheet' and allocate 25 minutes for the students to attempt the questions on the worksheet. The questions are related to all of the slides.

Slides 16 - 20 – Questions & answers

Go through the answers to the worksheet with the students, with the use of these slides. Recap any areas where students have particularly struggled to ensure learning takes place.

1. What are the three inter-related components which make up the fire triangle in order for fire to take place? Explain the role of each component.

- Source of fuel – required as something has to burn in order for the fire to take place.
- Source of oxygen – required to allow the combustion reaction causing the fire to take place.
- An initial ignition or source of heat to provide the energy for the reaction to start.

The slides can be used to cover the answers to the questions in a group situation or can be printed off and kept by the students for revision.

2. What are the three most common components of traditional gunpowder?

Charcoal, sulfur and potassium nitrate (often known as saltpetre).

3. What is the difference between an exothermic reaction and an endothermic reaction?

An exothermic reaction is a reaction whereby more energy is produced and released from the reaction than is required in order for the reaction to take place. An example of which is a combustion reaction. An endothermic reaction requires more energy for the reaction to take place than is created.

4. Using the following data, is the formation of water from hydrogen and oxygen an exothermic or an endothermic reaction? Bond energies in kJ/mol: H-H is 436, O=O is 496 and O-H is 463. Show your workings.

The reaction is exothermic producing a net enthalpy change of +484 kJ (242 kJ per mole of hydrogen burned or water formed).

Workings – Chemical equation is $2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$

Bonds broken (energy taken in/needed):

2 x H-H = 2 x 436

+

1 x O=O = 1 x 496

= 1368 kJ

Bonds made (energy produced):

4 x O-H = 4 x 463

= 1852 kJ

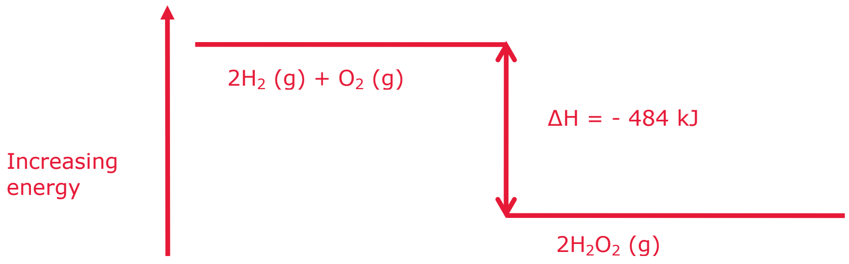
The overall energy change for the reaction is therefore:

-1368 kJ – −1852 kJ

= +484 kJ (or 242 kJ per mole of hydrogen burned or water formed). As the enthalpy change is positive for the overall reaction the reaction is exothermic.

5. Draw an energy diagram for the reaction in Q4.

Energy diagram for the formation of water from hydrogen and oxygen



The information in this energy diagram tells a Chemist that a net value −484 kJ of energy is required for the reaction to take place. As the ΔH is negative the reaction is exothermic.