Structure and Bonding
ANSWERS

The Basics

Atomic Structure
STOP AND CHECK (PAGE 5)

- The atom is made up of a central nucleus with protons and neutrons, then electrons whizzing around the nucleus in their electron shells.
- The first shell holds 2 electrons, then the second and third shells hold up to 8.
- The valence electron shell is the outermost shell of the atom, it's filled with special electrons called valence electrons.

Valence Electrons and Stability
STOP AND CHECK (PAGE 6)

- Atoms want a full valence electron shell to make themselves stable.
- Cations are formed by atoms losing electrons and gaining a positive charge. This makes them cations. Anions are formed the opposite way when atoms gain electrons and have a negative charge.

Covalent Bonds
STOP AND CHECK (PAGE 7)

- Covalent bonds are formed when nonmetal atoms can't find a metal atom to take electrons from, so they turn to other nonmetal atoms to share electrons.
- Covalent bonds form when two nonmetal atoms share electrons between themselves, rather than just stealing electrons from metal atoms.

Intermolecular Forces

STOP AND CHECK (PAGE 8)

- Intermolecular forces refer to the forces between molecules which hold different atoms and molecules together. These are also known as Van der Waals forces.

The Basics

QUICK QUESTIONS (PAGE 8)

- An atom is made up of a nucleus, which is where the protons and neutrons go, and electron shells, which is where the electrons go. Remember, the outermost electron shell is called the valence electron shell, which is filled up with special electrons called valence electrons.
- Atoms want a full valence shell so they can be stable. They accomplish this by either stealing, sharing, or giving away electrons until their outer electron shell (the valence electron shell) is full. So far, we've seen that nonmetal atoms share electrons with other nonmetals, and they steal electrons from metal atoms.
- Covalent bonds are intramolecular bonds that form between nonmetal atoms. These bonds are formed when nonmetal atoms share electrons with each other to fill their valence shells and become stable.
- Molecules are held together in the solid and liquid states by intermolecular forces, otherwise known as Van der Waals forces. These forces act between the molecules themselves and determine the substance's boiling points and melting points.

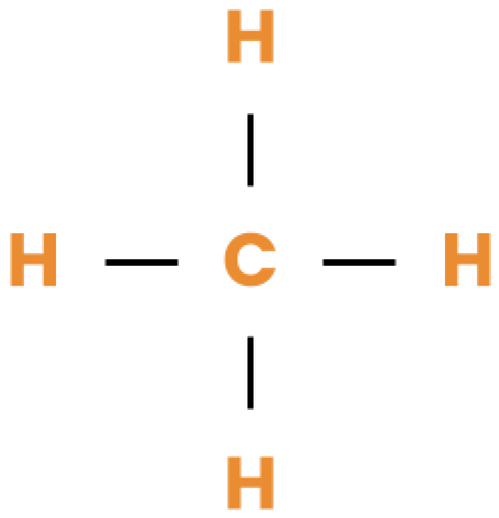
Lewis Diagrams

Lewis Diagrams

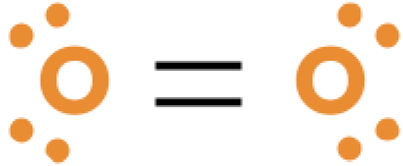
QUICK QUESTIONS (PAGE 11)

- Water (H_2O):

- Methane (CH_4):



- Oxygen (O_2):



Molecular Shape

VSEPR Theory

STOP AND CHECK (PAGE 13)

- First, we find the number of bonding and nonbonding pairs of electrons arranged around the central atom. This sounds a bit wordy, but it's really just every pair of dots in the Lewis diagrams we covered earlier. Once we know the number of bonding and nonbonding pairs of electrons around the central atom, we can figure out the shape of the molecule using our understanding of charges and 'likes attract like'.
- The two types of electron pairs are bonding and nonbonding pairs of electrons. The difference is that bonding pairs of electrons are involved in the bonds holding the molecule together while nonbonding electrons sit around their atom or ion.

Molecular Shapes

STOP AND CHECK (PAGE 17)

- H_2O is bent.
- CH_4 is tetrahedral.
- O_2 is linear.

Molecular Shapes

QUICK QUESTIONS (PAGE 17)

- The shape of the molecule is determined by how many pairs of bonding and nonbonding pairs of electrons there are around the central atom. Remember, double and triple bonds count as one set (they only repel slightly more, but otherwise act the same way as one pair). These pairs of electrons repel each other as far as possible to form the overall arrangement around the central atom, then the bonding pairs determine the shape of the electron. For example, a central atom could have 3 pairs of bonding and 1 pair of nonbonding electrons, so it would have a tetrahedral arrangement, but a trigonal pyramidal shape. That's why it's important to factor in bonding and nonbonding pairs of electrons, bonding and nonbonding pairs together determine the arrangement around the central atom, but the bonding sets determine the shape.

Polarity

Polarity

STOP AND CHECK (PAGE 19)

- Polarity is the "separation of charge". To be more precise, polarity is a separation of electric charge which results in a molecule or its chemical groups having an electric dipole or multipole. Don't worry, the only part of the definition you need to know that polarity is the separation of charge.
- Polarity can be applied to molecules and covalent when we see that polarity creates partial charges within the molecule. These partial charges have some important consequences that we'll be covering later on in the booklet.

Electronegativity

STOP AND CHECK (PAGE 21)

- Electronegativity describes the tendency of an atom to attract bonding electrons.
- Atoms to the top and right of the periodic table tend to have higher electronegativities. Ignore noble gases though, since they're unreactive.

Nonpolar Covalent Bonds

STOP AND CHECK (PAGE 23)

- Different atoms are needed to form polar bonds since different atoms have different electronegativities and pull bonding electrons with different strengths, which makes the bond polar.
- Non-polar covalent bonds form between identical atoms. Since the atoms are identical, their electronegativities are the same, and so the atoms pull on their bonding electrons with the same strength. Because of this, the electrons don't spend more time around either atom compared to the other, so no separation of charge occurs.

Polarity of Molecules

STOP AND CHECK (PAGE 25)

- First, we check if the shape of the molecule is symmetrical or asymmetrical. Asymmetrical molecules are always polar. Next, we check the polarity of the bonds. If the polarity of the bonds in the molecule doesn't cancel out (like with H_2O), then the molecule is polar. If the shape of the molecule is symmetrical and the dipoles cancel out, then the molecule is nonpolar.
- Symmetry is the decider of polarity. If it's not symmetrical in shape, then it's the symmetry in the dipoles of the molecule that determine polarity. Symmetry is the key to polarity; asymmetry creates a polar molecule, symmetry creates a nonpolar molecule.
- When there is more than one type of atom around the central molecule, the strength of the dipoles created in the bonds cannot cancel since they're not equal. There is no such thing as a nonpolar molecule that has different atoms around the central atom, since this is a form of asymmetry and asymmetry creates polarity.

Polarity

STOP AND CHECK (PAGE 26)

- Polarity refers to the separation of charge, when we talk about polarity, we're either talking about the polarity of molecules or polarity of bonds.

- Electronegativity describes the tendency of an atom to attract bonding electrons. It refers to how strongly an atom pulls on its bonding electrons and decides the polarity of bonds. Electronegativity increases as we move up the periodic table and increases as we move to the right of the periodic table. So, it increases with the group, decreases with the period.
- Polar covalent bonds are created when two atoms with different electronegativities (so any two different atoms) form a covalent bond, which causes the electrons to spend more time around the atom with the higher electronegativity, which causes a partial negative around that atom, and a partial positive charge on the atom it's bonded to. Non-polar bonds, however, are formed in covalent bonds between two of the same kind of atom. Since the atoms have the same electronegativity, they pull on the bonding electrons with the same strength, so the bond remains non-polar.
- Water is a polar molecule because of its bent/v-shaped shape. Since the shape of the molecule is asymmetrical, the dipoles created between the oxygen and the two hydrogens don't cancel out, leaving the molecule polar.
- Methane is nonpolar because every one of the polar bonds created between the central carbon atom and the surrounding hydrogen atoms cancels each other out, since they're all in opposite directions, due to the symmetry of the molecule. In CH_3Cl, however, the carbon to chlorine bond has a different polarity to the carbon to hydrogen opposite it so they don't cancel out. So, even though the molecule is symmetrical, the bonds don't cancel out and the overall molecule remains polar.

Types of Solids

Introduction to Solid Properties

STOP AND CHECK (PAGE 30)

- Solids are converted to liquids when their temperatures are raised to their melting points. Liquids are turned into gases when their temperatures are increased to their boiling points.

- Solubility refers to a solid (or solvent) that can be dissolved into a liquid (or solute). In general, if a solid can be dissolved, polar solvents must dissolve into polar solvents, and non-polar solvents must be dissolved into non-polar solvents.
- For a compound to be electrically conductive, it must have charged particles that can flow through the compound. This is conductivity. When a compound is conductive, it allows charged particles to flow freely throughout the compound, and this flow of charged particles is electricity. The particles can either be freely moving electrons or freely moving ions.

Molecular Structure

STOP AND CHECK (PAGE 32)

- Molecular solids are simply made up of molecules. Molecules themselves are made up of non-metal atoms bonded together by covalent bonds.
- Molecular solids are held together by weak intermolecular forces, i.e. Van der Waals forces.

Molecular Solid Properties

STOP AND CHECK (PAGE 33)

- Molecular solids have low melting and boiling points and aren't electrically conductive. Additionally, polar molecular solids dissolve in polar solvents like water, and non-polar molecular solids dissolve in non-polar solvents like cyclohexane.
- Molecular solids have these properties because they have weak intermolecular forces which don't hold the molecules together very strongly, so it doesn't take a lot of heat energy to separate the molecules, giving molecular solids relatively low melting and boiling points. They also aren't electrically conductive because, overall, molecules are not charged. Even polar molecules which have some charge remain uncharged overall, since the slightly positive and slightly negative charges on either side of those polar bonds overall cancel out, leaving the atoms charged but the molecule uncharged. Since there are no charges in dissolved molecular solids, no

charges can flow through dissolved molecular solids, so they are not conductive.
- Since water is a polar solvent, only polar molecules can be dissolved in water. So, by figuring out the polarity of the molecules in the molecular solid through structure diagrams, we can say that molecular solids made up of polar molecules can be dissolved in water.

Ionic Solid Structure

STOP AND CHECK (PAGE 35)

- Ionic solids are made up of at least one metal cation, and one non-metal anion.
- Ionic solids are held together by a lattice of positively charged cations and negatively charged anions. This is known as an electrostatic attraction.

Ionic Solid Properties

STOP AND CHECK (PAGE 37)

- Ionic solids have high melting points and boiling points and are electrically conductive when dissolved in a polar solvent. Additionally, ionic solids dissolve in polar solvents and don't dissolve in non-polar solvents. They are also very brittle and non-ductile.
- Ionic solids have such high melting points and boiling points because of their strong ionic bonds that hold the molecule together. Due to the bond strength, it takes a lot of heat energy to split up the ions to melt or boil them. Since ionic solids are made up of ions (which are really just charged atoms), when they're dissolved in a polar solvent like water these ions can flow freely, and thus ionic solids are highly conductive. Ionic solids are also very brittle and non-ductile because when the ions move slightly in the solid they end up tearing apart the whole structure, making ionic solids very easy to snap and very difficult to bend without breaking.
- Remember that electrical conductivity is dependent on the flow of charged particles. When an ionic solid is dissolved, the ions that make up the solid can flow freely and make the solution electrically conductive. However, when an ionic solid remains in solid form, the ions are held tightly in the lattice structure

of the solid by string ionic bonds, and can't flow. Since the charged particles can't flow, ionic solids are not electrically conductive until they're dissolved.

Metallic Solids

STOP AND CHECK (PAGE 38)

- Metallic solids are made up of metal atoms only.
- Metallic solids are held together by the electrostatic attraction between positively-charged metal nuclei and the delocalised atoms that flow through the solid. These bonds are called, conveniently, metallic bonds.

Metallic Solid Properties

STOP AND CHECK (PAGE 39)

- Metallic solids have very high melting points and boiling points, aren't soluble in polar or non-polar solvents, and are highly conductive. They're also highly ductile and malleable.
- Metallic solids have very strong metallic bonds holding them together, so it takes a lot of heat energy to melt or boil them. They're also insoluble in any solvent since the solvent can't overcome the strong metallic bonds, and therefore can't dissolve metals. Since metals have delocalised electrons that flow freely throughout the solid, they are also highly electrically conductive, since the negatively charged electrons can flow through the solid, creating an electrical current. Metallic solids are also highly malleable and ductile since the positive metal nuclei aren't held in a tight structure like an ionic solid, and can move over each other and stick when struck.

Diamond

STOP AND CHECK (PAGE 40)

- Diamonds are made up entirely of carbon atoms, where each carbon atom has a covalent bond to its four other surrounding carbon atoms.
- Diamonds are held together by the covalent bonds between the carbon atoms that make up the diamond.

- Diamonds have very high melting and boiling points, aren't soluble in polar or non-polar solvents and aren't electrically conductive.
- Diamonds have very high melting and boiling points due to the extremely strong covalent bonds that hold them together. They also aren't soluble because those covalent bonds are far too strong for any solvent to break apart, and they aren't conductive because the electrons in the solid are held tightly in the covalent bonds of the solid, so they can't flow to produce an electric current.

Graphite

STOP AND CHECK (PAGE 41)

- Graphite is made up of exclusively carbon atoms.
- The structure of graphite consists of 2D sheets of carbon atoms which are bonded through covalent bonds to three other carbon atoms, with each sheet being held together by Van der Waals forces.
- Graphite has high melting and boiling points, isn't soluble in polar or non-polar solvents, and is highly conductive.
- Since the 2D sheets of graphite are held together by extremely strong covalent bonds, graphite has high melting and boiling points, since it takes a lot of heat energy to break up those bonds. Graphite is also electrically conductive since the 'sea of electrons' between the 2D sheets of carbon atoms can flow freely through the solid, allowing an electrical current to be produced. Graphite also isn't soluble in polar or non-polar solvents since the strong covalent bonds that hold the 2D sheets together can't be overcome by a solvent, so graphite cannot be dissolved.

Silicon Dioxide (Silica)

STOP AND CHECK (PAGE 42)

- Silica (or silicon dioxide) is made up of silicon and oxygen atoms bonded together by covalent bonds.
- Silica is held together by the covalent bonds between silicon and oxygen atoms, with each silicon atom being bonded to 4 other oxygen atoms.

- Silica has a high melting and boiling point, isn't soluble in polar or non-polar solvents, and is not electrically conductive.
- Silica has high melting and boiling points since it is held together entirely by strong covalent bonds, the same as diamond. This means it takes a lot of heat energy to break up these bonds, giving silica its high melting and boiling points. Silica also isn't soluble in polar or non-polar solvents for the same reason as diamond and graphite. The strong covalent bonds between atoms in the molecule are just too strong for the solvent to overcome. Silica also isn't conductive for the same reason as diamond. Each electron in the solid is held tightly in the covalent bonds that hold the solid together, so they cannot flow and therefore cannot produce an electric current.

Types of Solids

QUICK QUESTIONS (PAGE 42)

- Water will freeze to form a molecular solid, magnesium will form a metallic solid, aluminium oxide will form an ionic solid, and diamond will form a covalent network solid.
- Water, when frozen into ice, will be held together by weak intermolecular forces, aka Van der Waals forces.
- Magnesium will be held together by metallic bonds.
- Aluminium oxide will be held together in a tight lattice structure, with ionic bonds holding it together.
- Diamond is held together by strong covalent bonds, with each carbon atom bonded to four other carbon atoms.
- In terms of melting/boiling points, ice has a low melting and boiling point due to its weak intermolecular forces, while magnesium, aluminium oxide, and diamond have high melting boiling points due to their stronger bonds. For solubility in water, the aluminium oxide will dissolve, while magnesium and diamond will not, since aluminium oxide has ionic bonds that can be overcome by water, while the metallic bonds in magnesium and covalent bonds in a diamond cannot be overcome. Ice will not dissolve since it already is water, so it would have to melt to mix with the water but would never really dissolve. For electrical conductivity, magnesium and dissolved aluminium oxide will be conductive, while diamond, ice and undissolved aluminium oxide will not be conductive. This is because ice, diamond, and undissolved

aluminium oxide do not have charged particles that can freely move throughout the solid, so an electrical current cannot be produced. Magnesium and dissolved aluminium oxide do, however, have charged particles that can flow, and thus they are electrically conductive.

- Diamond is a poor electrical conductor because all the electrons in the solid are held in the strong covalent bonds that hold the solid together, however, graphite is a good conductor because between the 2D sheets that make up the graphite there is a 'sea of electrons' that can flow freely throughout the solid, allowing it to be conductive.
- Metallic solids are far more malleable and ductile than ionic solids because when stress is applied to the solids that shift the structure of the solid, metallic solids stay together and ionic solids break apart. This is because metallic solids are held together by metallic bonds, which can form between any two metal atoms in the solid, so when the solid is shifted the bonds simply reform and the solid stays together. Ionic solids, on the other hand, are held together by ionic bonds, which can only form between a positive and negative ion, so when the structure of the solid is shifted, the bonds are broken and cannot reform between ions with the same charge, so the structure breaks apart.

Thermochemistry

Enthalpy and Enthalpy Change

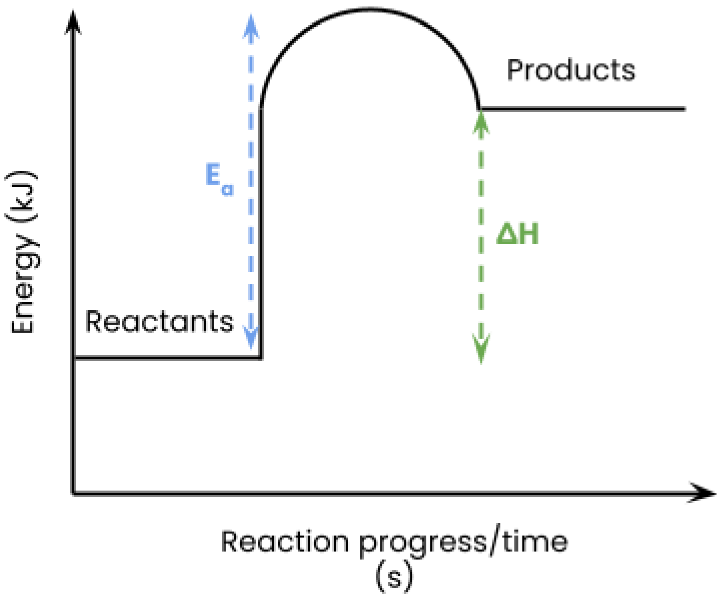
STOP AND CHECK (PAGE 40)

- Enthalpy is the total heat content of the system. This energy is stored in the bonds formed between atoms or ions.
- The system is whatever we happen to be looking at, while the surroundings are everything that isn't in the system; the rest of the universe.

Endothermic Reactions

STOP AND CHECK (PAGE 46)

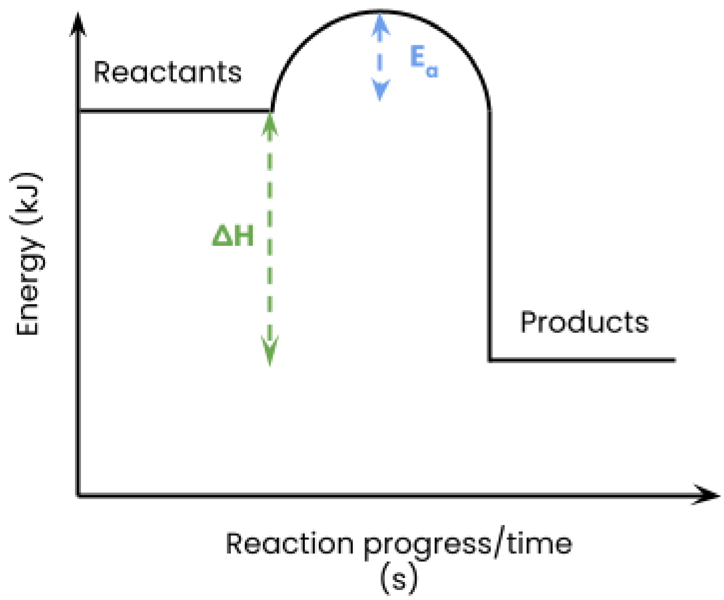
- During an endothermic reaction, energy is absorbed from the surroundings and enters the new bonds that are formed.



Exothermic Reactions

STOP AND CHECK (PAGE 48)

- During an exothermic reaction, energy is absorbed from the system and enters the surroundings.



Activation Energy

STOP AND CHECK (PAGE 48)

- The activation energy (E_a) is formally defined as “the energy barrier that is needed to be overcome before a reaction (between the particles) can take place”.
- The activation energy in endothermic reactions is, in general, higher than the activation energy in exothermic reactions.

Enthalpy Calculations Part I

STOP AND CHECK (PAGE 51)

- $n = \frac{m}{M}$, so just divide the mass (m) by the molar mass (M).
- $m = n \times M$, so multiply the number of moles (n) by the molar mass (M).
- $\Delta H = n \times \Delta_r H$, so multiply the number of moles (n) by the enthalpy change of the reaction.
- $\Delta_r H = \frac{\Delta H}{n}$, so divide the total enthalpy change of the reaction (ΔH) by the number of moles reacting (n).

Enthalpy Calculations Part II

STOP AND CHECK (PAGE 53)

- Enthalpy change of a reaction can be calculated by subtracting the enthalpy of products from the enthalpy of reactants:

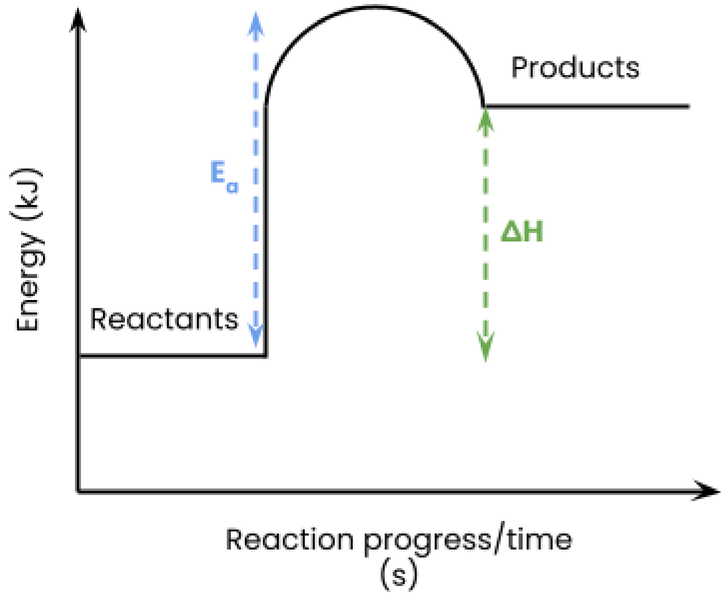
  $$\Delta_r H = \text{Enthalpy of reactants} - \text{Enthalpy of products}$$

  Firstly, to find the enthalpy of products and reactants, add up the average bond enthalpy of all the bonds of the reactants to find the enthalpy of reactants, then add all the average bond enthalpies of the bonds of the products to find the enthalpy of products.
- Bond enthalpy is the energy contained in that particular bond, which is the energy released when the bond is broken or absorbed when the bond is formed.

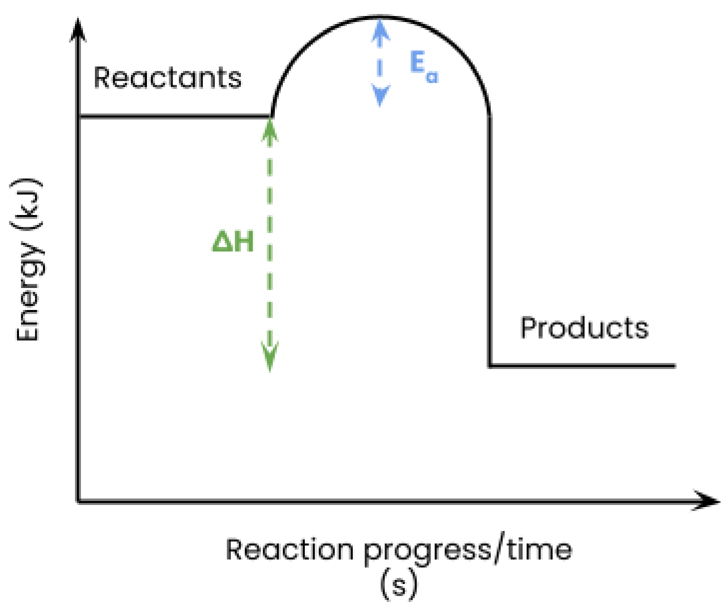
Thermochemistry

QUICK QUESTIONS (PAGE 53)

- Enthalpy change of the reaction is the difference in enthalpy between the reactants and products when only the number of moles specified in the reaction reacts. For example, if two moles of hydrogen react with one mole of oxygen to create one mole of water, then the enthalpy change of the reaction is the change in enthalpy for when only two moles of hydrogen and one mole of oxygen reacts to form one mole of water, not when any more reactants react.
- Endothermic reactions are characterised by relatively low activation energy and a negative enthalpy change in the reaction (so the enthalpy of the products is lower than the enthalpy of the products). Exothermic reactions also release energy from the system into the surroundings, increasing the temperature of the surroundings.



- Exothermic reactions are characterised by a relatively high activation energy and a positive enthalpy change in the reaction (so the enthalpy of the reactants is lower than the enthalpy of the products). Endothermic reactions also absorb energy from the surroundings into the system, decreasing the temperature of the surroundings.



- Activation energy is formally defined as "the energy barrier that is needed to be overcome before a reaction (between the particles) can take place". Activation energy is important because this is the energy that is required to get the reaction started. Without the reactants getting enough energy to overcome the energy barrier, the reaction doesn’t occur.

