

ADVANCED SUBSIDIARY GCE**CHEMISTRY (SALTERS)**

Skills for Chemistry: Open-Book Paper

2852/01For issue on or after: **14 February 2009**

Your report must be handed in by the deadline given by your teacher. You will be given two weeks to complete your report.

OCR Supplied Materials:

- Skills for Chemistry: Open-Book Paper Summary Sheet (inserted)

Other Materials Required:

None



This paper consists of two articles about chemistry in F1 car racing and intermolecular forces.

- Using between 800 and 1000 words, write a report in which you do the following:
 - **Discuss the chemistry involved in the burning of hydrocarbons to power a car engine. You should include a discussion of:**
 - **why compounds with different chain length and structures release different amounts of energy;**
 - **how the burning fuel produces energy transfers that power the car. [8]**
 - **Discuss how chemists improve petrol by using a variety of hydrocarbons. You should include discussion of:**
 - **what types of molecules are used as additives to improve fuel performance;**
 - **the meaning of the term octane number and the advantages of using isomers of octane in the fuel. [6]**
 - **Describe the types of intermolecular forces that act between molecules of hydrocarbons used in fuels and lubricants and discuss their effect on volatility and viscosity.**
Explain how lubricants work and why longer chain hydrocarbons are more likely to have good lubricating properties. [8]
 - **Discuss the materials that chemists have developed to enhance the performance of F1 cars and the safety of drivers. [4]**
- When you have finished writing your report, summarise the main **CHEMICAL** points of your report using up to 50 words on the Summary Sheet provided.

Before you start, read carefully the 'Notes for Guidance' on the next page.

This document consists of 12 pages. Any blank pages are indicated.

Notes for guidance

- 1 Your report should be of between 800 and 1000 words. An excess of 1000 words will indicate poor structure and unselective choice of material, so that full credit will not be available. You should indicate the number of words on each page in the margin at the foot of the page.
- 2 **Your report should demonstrate an understanding of the chemical issues involved. It should be aimed at an audience with an understanding of chemistry to Advanced Subsidiary GCE level. It should have a clear and helpful structure and should show evidence of planning.**
- 3 To help you understand the articles in this paper, you are encouraged to use books and other written sources of information, but **your report should be based closely on the information given in the question paper.**
- 4 Your report should be illustrated by pictures, diagrams, tables, flow charts, graphs, etc., as appropriate. Remember that these can often be used to replace words in the text. Illustrations should be relevant, concisely labelled and positioned appropriately with links to the text. The inclusion of large blocks of text in such illustrations is discouraged; any such text will be included in the word count (otherwise text in illustrations is excluded from the word count).
- 5 **You should take care to use technical and scientific terms correctly and to write in clear and correct English.**
- 6 You may hand-write or word-process your report. Remember that if subscripts, superscripts, arrows in equations, dots on radicals, etc. are not available on your word-processor, these must be drawn in correctly and clearly by hand.
- 7 At the end of your report, you should list clearly any sources you have used. Your list should contain at least **two relevant sources** as well as the articles supplied. (At least one of these should be from outside the Salters Advanced Chemistry course materials.) The list of references is not included in the word count.
- 8 You should refer to these references in your report where appropriate. Where you have incorporated material into your report which is copied directly from the articles in the question paper or from elsewhere, the **text must be annotated** and the source properly acknowledged. However, extensive copying from the articles or from other sources will not gain credit.
- 9 Your report should be written on unheaded A4 paper with a hole in the top left hand corner. Pages should be numbered and should have a **clear margin on the right hand side**. You should **write on one side of the paper only** and each separate sheet should be marked with your name or candidate number.
- 10 **Your summary should be written on the special sheet provided.**
- 11 When you have finished, tie the sheets together **loosely** or use a treasury tag, so that they turn over freely, with your Summary Sheet on the top. Do not use staples or paper clips and do not put your report in a plastic folder.

Article 1

The formula for speed: Kilojoules to horsepower

adapted from an article by Tony Hargreaves 'The Formula for Speed: Kilojoules to horsepower', *Chemistry Review*, 2003, Volume 13, Number 2.

Tension builds as cars line up at the start of a Formula 1 Grand Prix. Engines will rev to 19000rpm and will pump an explosive mixture of chemicals to set new performance records. Chemists have made a huge impact on the sport, from the bodywork to additives in the fuel.



Explosive reactions

The engine is the heart of the car. It converts chemical energy into kinetic energy (movement energy) through an organised sequence of chemical explosions. With the engine running at 19000 revs there will be 9500 explosions per minute in each cylinder. Which means, for an eight cylinder engine, over 1200 explosions per second! Every explosion must be smooth, not a brute force detonation. The engine is a most sophisticated vessel working at extremes of pressure and temperature.

Covalent bonds into energy

For chemists, it is the reactions of the fuel/air mixture to produce the explosions that interest us. Different motor vehicles burn different types of fuel. One of the main factors that affects the energy output of the fuel is the chain length of the hydrocarbon. Heavy vehicles such as lorries and some cars run on diesel fuel, which typically contains chain lengths of over 15 carbon atoms. Racing cars use mainly isomers of octane. Molecules with short chain length (for example isomers of pentane) are often added to make a more volatile petrol.

Glossary

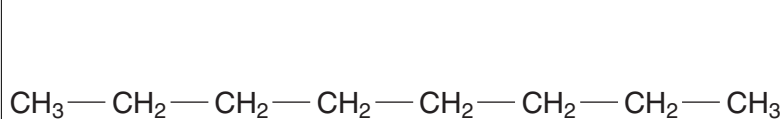
Enthalpy of combustion – the enthalpy change when 1 mole of fuel is burnt completely. It is measured in kJ mol^{-1} .

Stoichiometric – describes the ratio, in moles, in which reactants combine in chemical reactions. This is usually a simple, whole-number ratio.

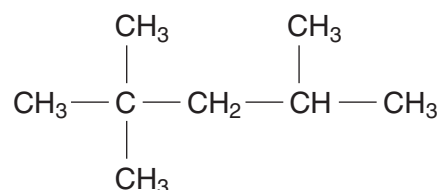
The energy output (which depends on the enthalpy of combustion) of the petrol is affected by the amount of energy taken in and given out when bonds are broken and formed during the combustion reaction. This means that different fuels have different energy outputs, as well as different physical properties. Values of combustion enthalpies can be calculated from bond enthalpy data, but do not always agree with data book values. This is because values of bond enthalpy such as those in Table 1 are average values, for example the C–H bond will have slightly different enthalpy values in different molecules. Also, calculations based on bond enthalpies do not take into account state changes, for example when a volatile liquid fuel vaporises before combustion, or when water vapour condenses afterwards. Standard enthalpy changes are measured under standard states, so water and some fuels are considered as liquids. These differences explain why isomers that contain the same bonds often have slightly different enthalpy changes of combustion (see below).

bond	average bond enthalpy / kJ mol^{-1}
C–C	+347
C–H	+413
C=O	+805
O–H	+464
O=O	+498

Table 1 Average bond enthalpies

Box 1 General equation for the combustion of isomers of octane

Straight chain octane
 $\Delta H_c = -5470 \text{ kJ mol}^{-1}$
 Boiling point = 126°C



Iso-octane (2,2,4-trimethylpentane)
 $\Delta H_c = -5461 \text{ kJ mol}^{-1}$
 Boiling point = 99°C

Isomers of octane are ideal fuels for the racing car because they vaporise easily. In older cars, the carburettor vaporised the fuel, but today this task is now performed by computer controlled fuel injection systems. The reaction that occurs in the cylinder is shown above. The exact ratio of fuel to oxygen that is supplied to the engine varies for different vehicles.

Hence the fuel injection system must be finely tuned: too much air and the engine will burn out before the first lap; too little air and the car will be lagging behind, churning out unburnt hydrocarbons from its exhaust. The role of the engine is to transfer chemical energy in the fuel-oxygen system to kinetic energy to power the car.

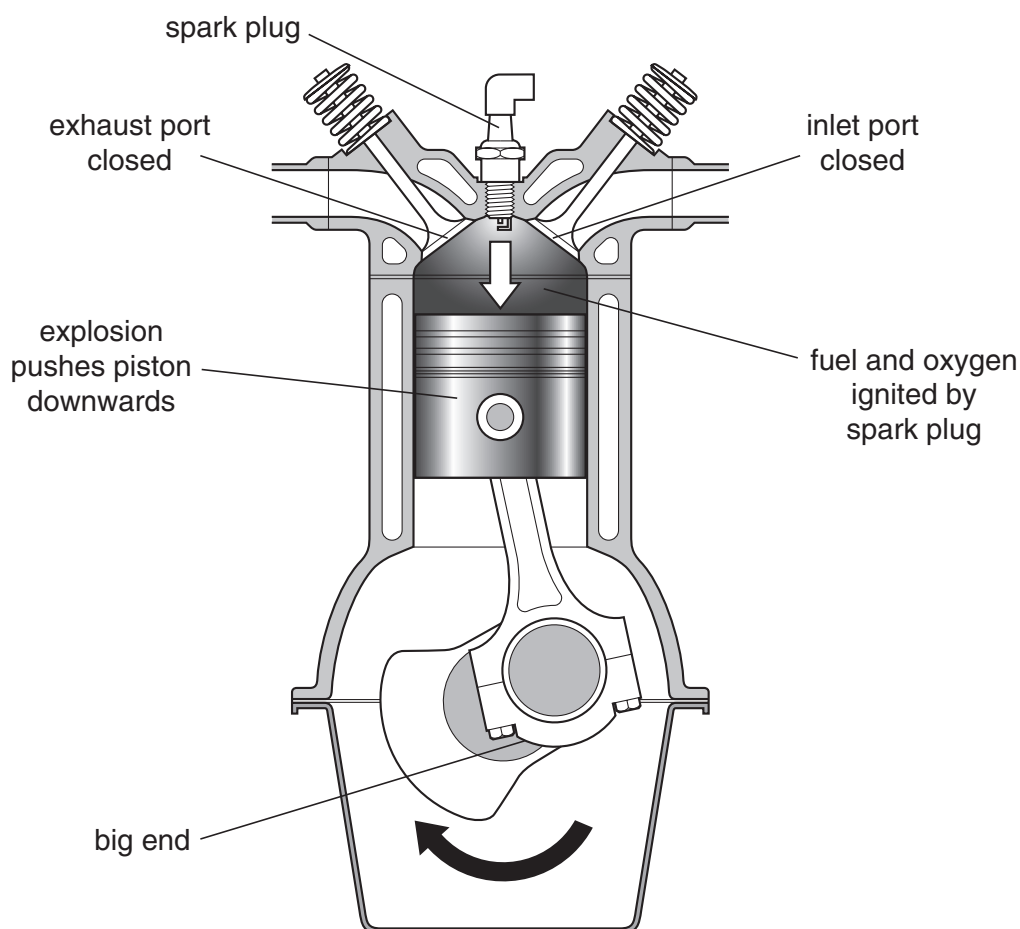


Fig. 1 F1 racing cars usually have piston engines much like an ordinary car engine. This type of engine converts chemical energy in the petrol to the kinetic energy for movement. The energy conversion takes place in the cylinders when a mixture of petrol and air explodes (see equation 1)

Cold moles to hot moles

We see that in the combustion equation (Box 1, equation 1) there is an increase in the number of moles of gas from 27 to 34, and this causes a small pressure increase. The most important feature of this reaction is the heat released (enthalpy of combustion). The energy is produced in milliseconds and causes a huge temperature rise which, in turn results in a dramatic pressure increase, due to the expansion of the gases when they heat up quickly. All this takes place in the cylinders (Fig. 1) and delivers a massive force upon the pistons. As the pistons are forced down inside the cylinders, they push connecting rods to turn the crankshaft. Thus the energy transfer sequence goes

chemical energy → heat energy → kinetic energy

As the piston moves down, the volume expands and the gases cool. They are discharged to the atmosphere as exhaust gases – cooler than in the explosions but still very hot.

Fuel chemistry

Equation 1 is a simplification of the engine's combustion reaction. In fact, many hydrocarbons

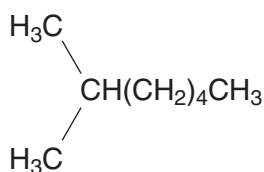
are involved because petrol is not a single compound but a mixture including hydrocarbons with different structures: alkanes, alkenes, aromatics and isomers of each group. Using a mixture of hydrocarbons, decreases the likelihood of 'knocking' due to auto-ignition. This increases the **octane number** of the fuel so that the car engine can operate at a higher compression ratio. Generally, shorter chain alkanes and branched chain alkanes have higher octane numbers than longer, straight chain alkanes. Iso-octane (2,2,4-trimethylpentane) is a branched alkane with a very low tendency to knock, it is used as the reference for measuring other compounds. It is given an octane number of 100. Heptane, which auto-ignites easily, is given an octane rating of 0. So a petrol blend with an octane rating of 97, for example, knocks at the same compression ratio as a mixture of 97% iso-octane with 3% heptane.

For racing cars it is common practice to put in **additives** to improve combustion characteristics and so increase performance. Some of the additives used are shown in Box 2. As you can see, all the additives contain oxygen and this enables combustion to take place more efficiently.

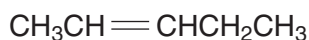
Box 2 Compounds in fuels

Petrol is a mixture of hydrocarbons obtained from the distillation of petroleum. Sometimes oxygen-containing molecules are added to improve the fuel's performance. In F1 racing there are strict rules on fuel composition, laid down by the Federation Internationale de l'Automobile (FIA) which is the governing body for F1 racing.

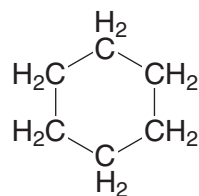
Hydrocarbons C4 to C9: Alkanes, straight chain and branched (e.g. octane and 2-methylheptane); cycloalkanes (e.g. cyclohexane); alkenes (e.g. pent-2-ene); aromatics (e.g. methylbenzene).



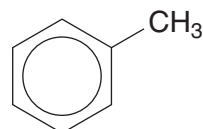
2-methylheptane



pent-2-ene



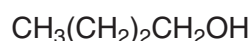
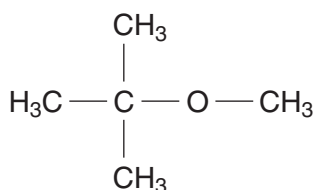
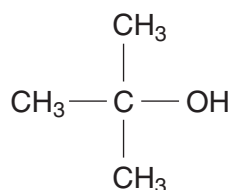
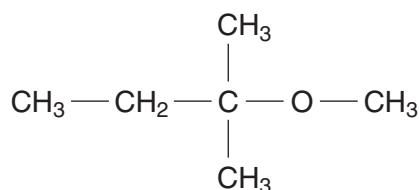
cyclohexane



methylbenzene

Box 2 cont.

Additives: alcohols (e.g. methanol, ethanol, propan-1-ol, butan-1-ol, 2-methylpropan-2-ol); ethers (e.g. 2-methoxy-2-methylpropane, 2-methoxy-2-methylbutane).

**butan-1-ol****2-methoxy-2-methylpropane****2-methylpropan-2-ol****2-methoxy-2-methylbutane****Lubrication**

With all the metal parts rubbing against each other at high speed — speeds can reach hundreds of miles per hour in bearings and cylinders — efficient lubrication is essential. The most widely used lubricants are hydrocarbon oils obtained, like petrol, from distillation of crude oil, but the molecules used as lubricants are long-chain hydrocarbons. The lubricants must adsorb onto the metal surface to prevent metal-metal contact and they must also stay viscous at extreme temperatures.

To get the best lubricating properties, chemists study the intermolecular attractions between molecules and metal surfaces and also between the molecules themselves.

Without lubrication, the friction between moving parts would be so intense that the metal parts would melt and weld together. Despite the best efforts of chemists and engineers, sometimes there is a lubrication failure and the engine catastrophically disintegrates. Oil is tested trackside to see if small particles of metal are present, which is an indication that wear is taking place and lubrication failure could be imminent.

Tyres

Maximum friction between tyres and track is essential to avoid wheel spin. Untreated natural rubber is too soft for tyres. It is vulcanised by heating with sulphur to produce vulcanised rubber which is harder and stronger due to cross links formed in the rubber structure. To prolong the tyre life, antioxidants are added which stop the tyre degrading. The tyres are composite materials, reinforced with cords of nylon or polyester with steel wire 'beading' to attach the tyre to the wheel rim.

Tyres are usually nitrogen filled, which expands less than air when heated because it does not contain water.

Car body and structure

Rapid acceleration (0 to 200mph), high speed cornering and severe braking during races put the F1 cars under enormous stress. In the early days of F1 racing, cars had lightweight aluminium bodies, but these were weaker than today's cars. Polymer chemists have developed polymers and composites to replace them. Synthetic polymers such as epoxy resins are the main components of fibre-reinforced composites and the polymers bind with glass fibres or carbon fibres to form a lightweight, high strength matrix. These composites are often superior to metals for weight and strength.

Driver protection

Protecting the driver in case of crash or fire is a major consideration. Driver helmets must be lightweight but capable of withstanding severe impact. Again, fibre-reinforced polymers are ideal. Textile chemists have made flame retardant clothing by treating fibres to stop them from burning. Specially treated cotton clothing is worn by F1 drivers. Cotton, which is a natural polymer of cellulose, has glucose as its monomer

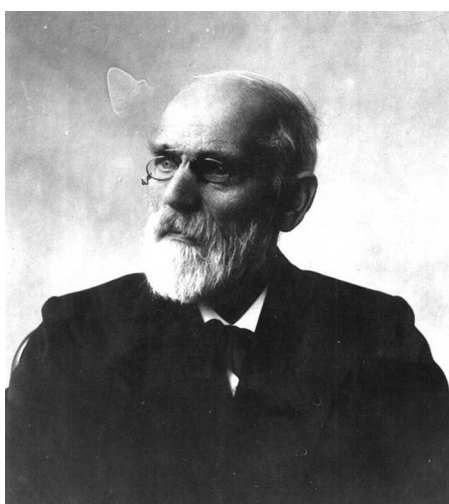
and so it is very easily combusted. To make it flame retardant, it is treated with tetra(hydroxymethyl) phosphonium chloride (THPC). The THPC bonds with the cotton fibres and does not wash off when laundered. The phosphorus in the molecule bonds with the cellulose in the cotton if it catches fire and forms a charred layer. The charred layer prevents further heat damage to the driver's body.

Adapted article 'The formula for speed: Kilojoules to horsepower'
Chemistry Review, November 03.

What are van der Waals forces?

adapted from an article by Chris Otter (formerly Prior) 'What are van der Waals forces?', *Chemistry Review*, 2003, Volume 13, Number 1.

The term 'van der Waals forces' is often encountered in chemistry as a phrase to describe intermolecular forces, that is the forces *between* molecules, as opposed to forces *within* molecules. The term is named after the Dutch scientist, Johannes van der Waals, who was awarded the Nobel prize for physics in 1910.



Johannes van der Waals

There are three main types of intermolecular forces, dipole–dipole interactions, hydrogen bonds and instantaneous dipole–induced dipole interactions.

An understanding of the forces that act between molecules enables chemists to match molecules to specific uses. This is because intermolecular forces determine the physical properties of compounds. In general terms, the stronger the forces acting between molecules, the higher the boiling point and melting point and the more viscous the compound will be. For example, **lubricating oils** need to be viscous liquids within the whole range of operating temperatures of the car engine, from when the car 'cold starts' to when it reaches its hottest operating temperatures. Lubricating oils also need to cling to the metal engine parts so that the metal parts are fully protected from the damage that friction will cause if metal rubs on metal. An understanding of

intermolecular forces enables chemists to advise engineers on the type of molecules that are most likely to work well.

Dipole–dipole interactions

These are classified into two main types: **permanent dipole–permanent dipole** and **permanent dipole–induced dipole** interactions.

Permanent dipole–permanent dipole interactions

If a molecule is made up of atoms of differing electronegativities, then a dipole will be created, that is, there will be a permanent uneven distribution of charge within the molecule. If a molecule with a dipole approaches another such molecule, they will align in order to attract each other. This is called a permanent dipole–permanent dipole interaction and is the main force holding polar molecules together in a liquid.

Glossary

Electronegativity – the measure of the tendency of an atom in a stable molecule to attract electrons within bonds.

Permanent dipole–induced dipole interactions

If a molecule with a permanent dipole (see above) for example HCl , approaches another molecule with no permanent dipole, for example Cl_2 , electrons in the non-polar molecule will be repelled from the negative end of the polarised molecule, producing what is known as an induced dipole.

Hydrogen bonding

Hydrogen bonds are the **strongest** of the intermolecular forces described here. They are really a special type of dipole–dipole interaction. If hydrogen is bonded to a highly electronegative atom such as nitrogen, oxygen or fluorine, then a strong dipole is established.

The hydrogen bond formed is essentially an extra strong permanent dipole–permanent dipole interaction.

Instantaneous dipole–induced dipole interactions

Sometimes called dispersion forces or London forces, these are the **weakest** type of intermolecular attractions. They act between *all* atoms and molecules and are a result of the electrons in atoms constantly moving. As the electrons in an atom move, a dipole will be created as the electron distribution becomes asymmetrical (uneven). The dipole will be rapidly changed as the electrons continue to move, creating a new dipole. Consequently this type of dipole is called an instantaneous dipole. During the fraction of a second that this dipole does exist it can cause another dipole to form in an adjacent atom. This new dipole is called an induced dipole. Since the electrons are constantly moving, these instantaneous dipole–induced dipole interactions will be constantly changing direction (see Fig. 1).

The more electrons there are in the atoms involved, the greater the instantaneous dipole–induced dipole interactions.

Instantaneous dipole–induced dipole interactions between *molecules* are relatively strong because there is a large electron ‘cloud’ that can be distorted. Alkane molecules are typical of molecules that have this type of interaction. The larger the molecule, the more electrons there are and the stronger the instantaneous dipole–induced dipole forces because there can be a greater distortion of the electron cloud. As the number of carbon atoms increases, so do the number of electrons which in turn increases the induced dipole–instantaneous dipole forces, leading to higher boiling points and greater viscosity for heavier alkanes. This explains why very small alkanes such as methane, CH_4 , are gases; molecules such as heptane, C_7H_{16} and octane, C_8H_{18} , are liquids that vaporise easily, and heavy alkanes with over 20 carbon atoms are very thick, viscous liquids with higher boiling points that are suitable for use as lubricants. Molecules with chain lengths between these extremes, such as octane, are often used as liquid fuels because their volatilities allow them to vaporise easily. Instantaneous dipole–induced dipole interactions can also be formed between large hydrocarbon molecules and metals, so that the hydrocarbon is attracted to and hence ‘clings’ to the surface of the metal.

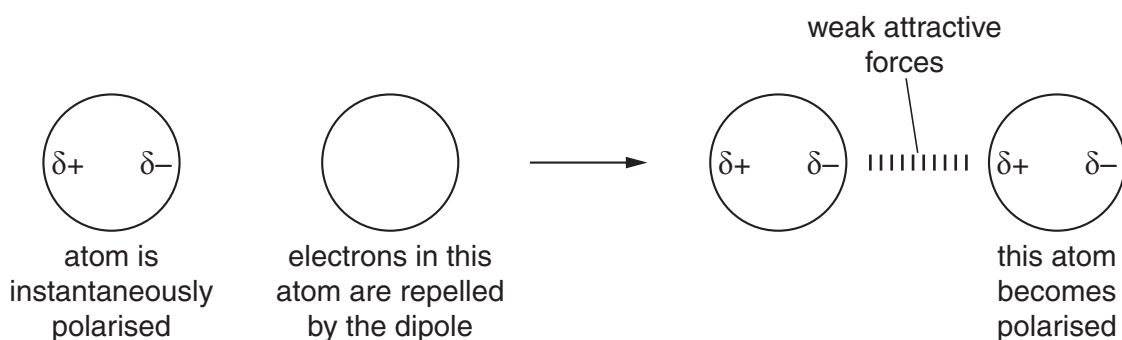


Fig. 1 Instantaneous dipole–induced dipole interactions

Instantaneous dipole–induced dipole forces between molecules are stronger when there are more points of contact between molecules. This explains why longer chain alkanes have stronger forces between their molecules, leading to higher boiling points. Branched chain alkanes do not line up as well as their straight chained relatives, and so there are fewer points of contact between atoms of different molecules. This explains why branched chain alkanes have lower boiling points than straight-chain isomers with the same molecular formula. The more volatile nature of branched chain alkanes is one of the reasons they are ideal for use in fuels.


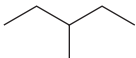
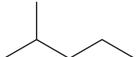
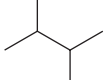
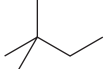
alkane	skeletal formula	boiling point/K
hexane		342
3-methylpentane		336
2-methylpentane		333
2,3-dimethylbutane		331
2,2-dimethylbutane		323

Table 1 Boiling points of the isomers of C_6H_{14}

Viscosity of lubricating oils

The viscosity of most liquids decreases with temperature as the molecules have more energy to overcome the intermolecular forces. (Treacle, for example, becomes more 'runny' as it is heated up.) In a vehicle engine this is undesirable, as the lubricating oil will not do its job if it is too thick at low temperatures or becomes too thin at high temperatures. Modern lubricating oils are called 'multi-grade' because their viscosity stays roughly the same with increasing temperature. These oils contain polymer molecules dissolved in them. At low temperatures these polymers are coiled up with instantaneous dipole–induced dipole forces holding the coil in shape. This means that the viscosity is not too high, as there are relatively few intermolecular forces between coiled molecules. As the oil warms up each polymer molecule begins to unwind into a long chain. The forces that hold each chain coiled up are broken but more intermolecular forces now form with other chains. Thus the contribution of the polymer molecules to the viscosity of the oil increases and counteracts the 'thinning' of the rest of the oil.

So what is the problem with the term van der Waals forces?

Some chemists consider the term to include only instantaneous dipole–induced dipole interactions while others consider van der Waals forces to be instantaneous dipole–induced dipole interactions and dipole–dipole interactions. A small minority of chemists also include hydrogen bonding under the heading of van der Waals forces.

Adapted article 'What are van der Waals forces'
Chemistry Review, November 03.

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