Looking at Motor Oil

Contents: Information and questions on the function of motor oil in an engine, and the problems involved in formulating an efficient oil. Optional practical work investigating the change of oil viscosity with temperature.

Time: 1 period or less without practical work; 2 periods or more if practical work is used.

Intended use: GCSE Chemistry and Integrated Science. Links with work on petroleum, hydrocarbons and alkanes.

Aims:

- To complement prior work on hydrocarbons and alkanes
- To show the varied functions of motor oil
- To show the role of scientists in designing and formulating a product such as motor oil
- To provide opportunities to practise skills in reading and comprehension, and certain practical skills, including accurate timing and safe heating of a liquid.

Requirements: Students' worksheets No. 205. For practical requirements, see below.

The unit is designed to stand alone without the practical work, but it is recommended that the experiment be used as well if this is at all possible. If apparatus is limited, it could be done as a demonstration.

Background information

Designing an oil

A multigrade oil is designed to be thin at low temperatures yet thick enough to be effective at engine operating temperatures. It does this by viscosity improvers, which are polymers of four types: polyisobutenes, polymethacrylates, ethene/propene copolymers and alkene/styrene copolymers. These are added to the 'base oil', which forms the basis of the lubricating oil blend. The polymers coil up at low temperatures and so increase the viscosity only slightly, but as the temperature rises they interact more strongly with the base oil and slowly uncoil, thus helping to counteract the decrease in viscosity of the base oil.

In the students' materials, the viscosity of oil is explained in terms of 'tangling' of molecules. The situation is of course more complex than this: viscosity is related to intermolecular forces, and longer chains have higher intermolecular forces due to their larger number of points of contact.

What jobs does an oil do?

Besides viscosity improvers, modern oils also contain other additives. These are summarised in the table below.

Job of additive	*Chemical type*	*Action*
Anti-oxidant	Phenols, arylamines	The compounds react sacrificially to terminate chain reactions that would result in deterioration of the oil due to oxidation.
Anti-wear	Compounds containing P or S	The additive is absorbed onto metal surfaces, helping to prevent wear should contact occur.
Corrosion inhibition	Organic compounds with N and S included. Basic detergents	The inhibitor acts to remove harmful species formed in the engine. For example, basic detergents neutralize acids formed in combustion.
Dispersant	Polar copolymers	The dispersant acts to keep solid particles in suspension until they reach the oil filter and are removed.
Anti-foam	Silicone fluids	Mechanical agitation causes foam, which these fluids break up as it starts to form.

During use these additives are gradually consumed, the viscosity improver molecules break down due to mechanical shear forces, and the oil becomes contaminated with wear debris, moisture, dust, combustion products and unburnt fuel. All these degrade its quality and limit its life, which in the case of car engines is normally about 6000 miles or six months. The engine may also burn some oil, which will make topping-up necessary — if possible, this should be done using the same oil in order to ensure that additives are compatible.

The practical

This practical is somewhat messy, and for this reason teachers may prefer to demonstrate it, though many trial schools found it an effective class practical.

Each group will require:
- measuring cylinder (250cm^3)
- beaker (400cm^3)
- motor oil
- thermometer (0 to 100°C)
- stopclock, accurate to 0.1s
- weighted sphere (see below)
- magnet
- tripod and gauze, bunsen burner, heatproof mat

The descent of a small sphere through oil is timed at different temperatures. The falling object must satisfy three criteria.:

- It must be a sphere, to ensure laminar flow
- It must be magnetic, to ensure ease of retrieval
- It must not be too dense, to ensure that its descent is not too rapid.

This last criterion precludes the use of such things as steel ball bearings, but a molecular models hydrogen atom (a solid plastic sphere of approximate diameter 1.5cm) with a self-tapping screw inserted has been found to give good results. (Trial results are given below.)

With the set-up described, times of 1.0 to 5.0s must be measured with reasonable accuracy, hence the need for an accurate stopclock.

The grade of oil to be used is not critical — any single or multigrade motor oil is quite satisfactory. The conditions of the experiment do not enable the difference in viscosity/temperature relationships between single and multigrade oils to be demonstrated. Heating the oil directly is not dangerous since motor oils have a high flashpoint, although any spills onto the gauze may cause some smoke.

Under no circumstances should the oil be heated above 100°C. Above this temperature any water present in the oil may vaporize explosively, with dangerous consequences.

Trial results using Shell Super Motor Oil:

Oil temperature/°C	24	32	41	51	58	68
Average time/s	4.11	2.76	1.97	1.56	1.43	1.22

Cleaning the apparatus

After the experiment the apparatus will be very oily and should be soaked for several hours in hot water with plenty of detergent.

Treatment of results

The relating of 'time to fall' to viscosity is treated very simply. It may be derived, if wished, from Stokes Law and the relationship $v=x/t$. Obviously the viscosity of oil falls as temperature rises, this fall being most noticeable in the range 20°C to 40°C.

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LOOKING AT MOTOR OIL

A lot of people do not think very much about the oil in the engine of their family car. They know that the oil must be changed when the car is serviced, and that it sometimes needs 'topping-up' but that is usually about all. To carry on working properly with so little attention, oil must be carefully designed (or 'formulated') by scientists.

In this unit you will look at some of the ways an oil is designed. You may also do an experiment to test a motor oil's viscosity.

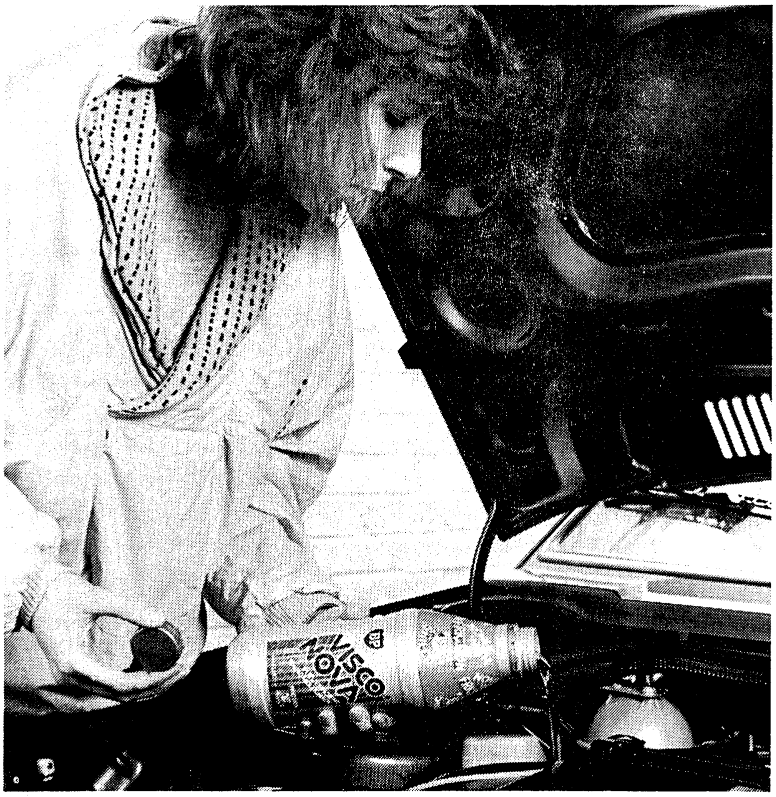

Figure 1 'Topping-up' the oil

Designing an oil

In a car engine, pistons move up and down inside cylinders. One of the main jobs of motor oil is to *lubricate* the pistons so they move smoothly (Figure 2).

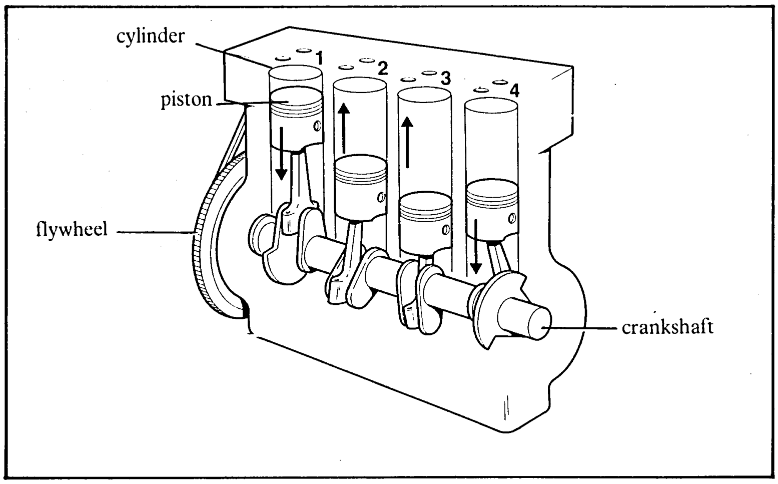

Figure 2 A four-cylinder petrol engine

Questions

1. *How does the viscosity of most liquids (for example, treacle) change when they are heated?*
2. *Why is it important for motor oil designers to know how the viscosity of motor oil changes with temperature?*

For good lubrication, the oil must have the right *viscosity* (thickness).

Your teacher may ask you to do an experiment to investigate the viscosity of motor oil. You will investigate how its viscosity changes with temperature. If you are doing the experiment, do not go on to the next section until you have completed it.

Viscosity and temperature

If you have done the experiment, you will know that

motor oil gets thinner (less viscous) at higher temperatures.

Oil must work at a wide range of temperatures. In the icy cold of a winter's morning its temperature may be as low as minus 15°C. At the operating temperature of the engine it will be between 90°C and 100°C. Any change in viscosity affects the way oil behaves and how it lubricates the engine's moving parts.

Question

3 How will the oil's viscosity change over the temperature range from minus 15°C to 100°C?

A thin oil does not 'cling' well to moving surfaces, but it is easy to circulate round the engine quickly. A thick oil clings well, but circulates sluggishly. This leads to the following advantages for thick and thin oil:

Thick oil
Better engine protection
Less oil used up
Quieter running

Thin oil
Easier cold starting
Faster circulation round the engine
Saves petrol.

Questions

4 Why do thin oils give easier cold starting?

5 Why do thick oils give better engine protection?

To overcome the problem of the wide range of temperatures in which oil has to work, scientists have developed special oils called **multigrade** oils. A multigrade oil is specially formulated so that its viscosity does not change too quickly as the temperature rises. The oil is thick enough to coat and lubricate moving surfaces at high temperatures. At low temperatures it stays thin enough to make sure that the engine will turn easily.

How do multigrade oils work?

Motor oils contain a mixture of carbon compounds. Most of these compounds are alkanes with chains of about 30 carbon atoms. These chains get tangled up, which makes it more difficult for the oil to flow. The more tangling, the more viscous the oil will be.

Multigrade oils include special substances called **viscosity index improvers,** or **VIs** for short. The molecules in VIs behave in different ways at different temperatures (Figure 3).

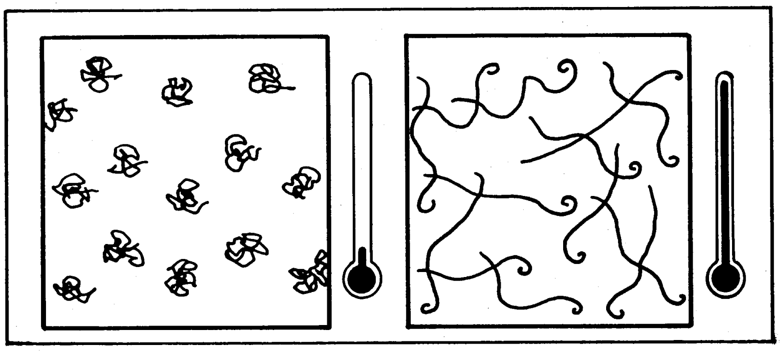

Figure 3 Molecules of VI at low (left) and high (right) temperatures

Question

6 *How do VIs help to increase the viscosity of an oil at high temperatures, without making it too thick at low temperatures?*

Measuring the viscosity of oil

Oil viscosity can be measured in many ways, but the best known system uses **SAE numbers.** (SAE stands for Society of Automotive Engineers, an American organization.) Single grade oils have one SAE number, 20, 30, 40 or 50. The higher the number, the higher the viscosity. Multigrade oils have two SAE numbers. The first (5W, 10W, 15W or 20W) shows the viscosity at minus 18°C. The 'W' stands for winter. The second number gives the viscosity at 99°C. Again the higher the number, the higher the viscosity. A typical multigrade oil would be rated 20W/50. The larger the range, the thinner the oil is for winter starting but the better lubricant it is at high temperatures.

Question

7 *How would the SAE number of an oil change if the carbon chains in it were lengthened?*

What jobs does an oil do?

1 *Lubrication* This is the most important job. A thin film of oil between moving surfaces is vital to prevent friction. Without the oil (a) the engine would be hard to turn; (b) the surfaces rubbing together would overheat; (c) the surfaces would wear away.

2 *Cooling* The oil must be able to remove heat from hot parts of the engine and transfer it to the cooling system.

3 *Taking away contaminants* As the engine wears, tiny particles of metal may be carried round the engine, causing damage. The oil must carry these particles to the oil filter, which traps them.

4 *Preventing rust and corrosion* When fuel burns, some of the things produced may be very harmful to the engine. For example, diesel fuel makes a small amount of sulphuric acid! The oil must react with these products to prevent corrosion.

5 *Forming a gas seal* The piston must form a tight fit in the cylinder so that no gases can escape. The oil helps to do this, by forming a gas seal.

No one substance could do all these jobs, and a good oil is a complicated mixture of substances. In fact, you could call it 'Liquid Engineering'!

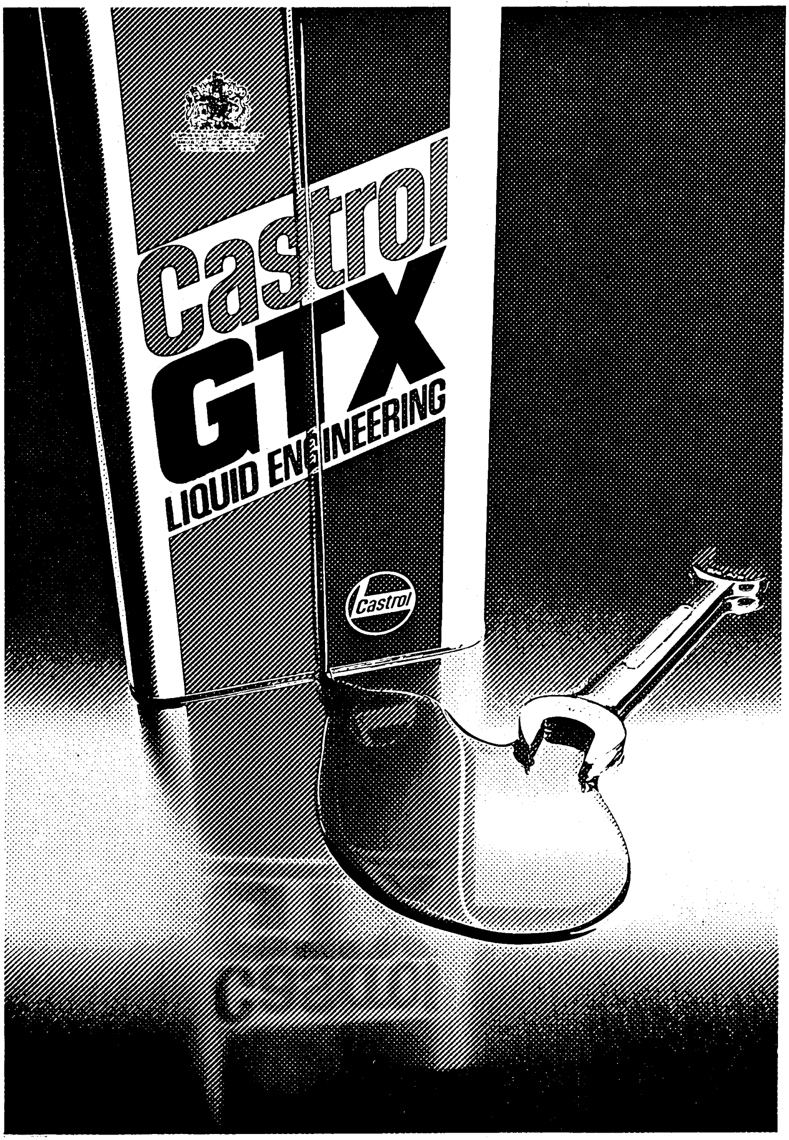

Figure 4

Questions

8 *Different jobs need different oils. What properties should oils for the following jobs have?*
(a) *Oiling a sewing machine*
(b) *Oiling a bicycle*
(c) *Oiling a ship's propellor shaft?*

9 *Water flows well and is very cheap. Why is it not often used as a lubricant?*

Experiment: Investigating the viscosity of oil

In this experiment you will be looking at the way the viscosity of motor oil changes as the temperature changes.

You will need:
250 cm^3 measuring cylinder
400 cm^3 beaker
motor oil
thermometer (0° to 100°C)
digital stopwatch (with 0.1s accuracy)
weighted sphere
magnet
tripod and gauze, bunsen burner, heatproof mat.

What you do

A Pour oil into the measuring cylinder until it is about 1cm from the top of the cylinder.

B Take the temperature of the oil and record it in a table like the one below.

C You are now going to investigate how long it takes the weighted sphere to travel through the oil from the top of the cylinder to the bottom. Take the weighted sphere and hold it just above the surface of the oil in the cylinder. Drop the sphere into the oil, at the same time starting the stopwatch. Stop timing when the sphere reaches the bottom of the cylinder. Record how long it took for the sphere to travel from the top of the cylinder to the bottom.

D Using the magnet, bring the sphere back up to the top of the cylinder. Remove it, and repeat the experiment (Figure 5).

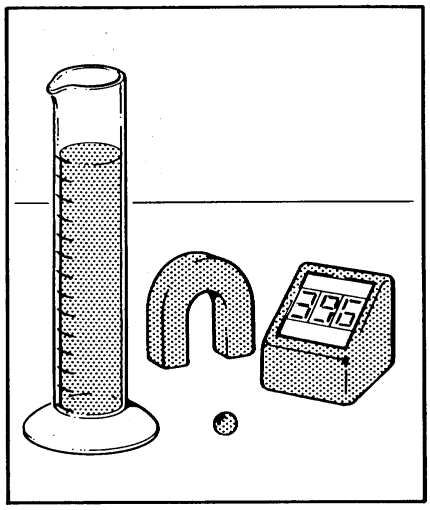

Figure 5 Equipment to investigate the viscosity of oil

You should do this until you have three results that agree quite closely. Work out the average of these three results, and record it in the table as follows:

Oil temperature/°C	*1st reading*	*2nd reading*	*3rd reading*	*Average*

E Now pour the oil into the beaker and heat it *gently* to about 30°C. Stir it gently with the thermometer while you heat it.

CAUTION — Wear goggles for heating and pouring

F Pour the oil back into the measuring cylinder to within about 1cm of the top, and record its exact temperature.

G Now drop the weighted sphere through the oil in the same way as before. Record the average time for this temperature in your table.

H Carry on heating the oil and timing the sphere at temperatures of about 40°C, 50°C and 60°C, recording the exact temperature of the oil in the measuring cylinder each time. **Do not go above 60°C.** Record all the results in your table.

> **CAUTION**
> At these higher temperatures you must be very careful with oil — hold the beaker with a cloth or paper towel when pouring, and be careful not to splash. If hot oil falls on you, quickly wash it off with lots of water. **Do not heat the oil above 60°C.**

I Now plot a graph of average fall time (y-axis) against temperature (x-axis) (Figure 6). Draw a smooth curve through the points.

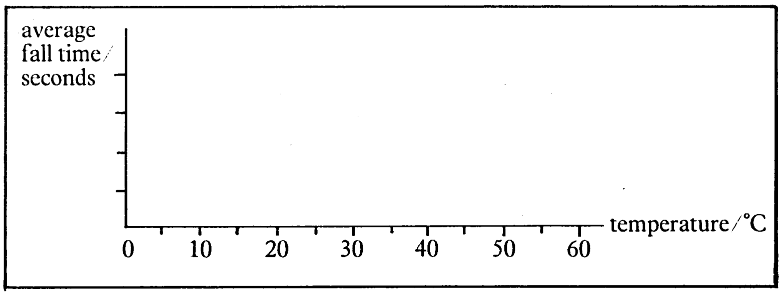

Figure 6

Looking at the results

The more viscous the oil, the longer the sphere will take to fall through it. This means that if the viscosity of the oil is large, the time taken for the sphere to fall is also large. So your graph represents the viscosity of the oil at different temperatures.

How does the oil's viscosity change as the temperature rises?