Oxford Cambridge and RSA

Tuesday 12 October 2021 – Morning

A Level Chemistry B (Salters)

H433/02 Scientific literacy in chemistry

Time allowed: 2 hours 15 minutes

You must have:
- a clean copy of the Advance Notice Article (inside this document)
- the Data Sheet for Chemistry B

You can use:
- a scientific or graphical calculator
- an HB pencil

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number | | | | | | Candidate number | | | | |

First name(s) ____________________

Last name ____________________

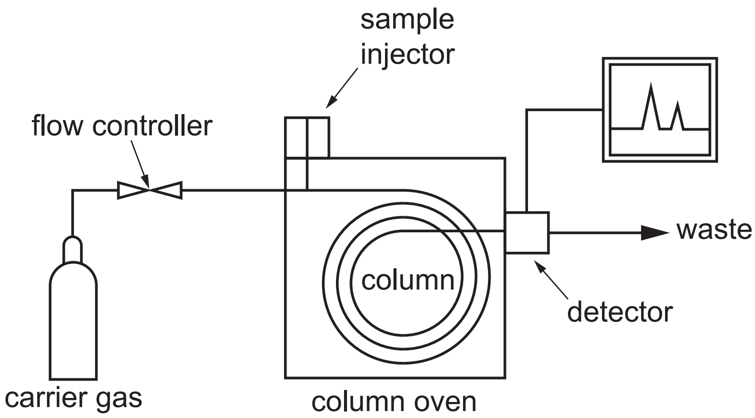
INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **20** pages.

ADVICE
- Read each question carefully before you start your answer.

Answer **all** the questions.

1 Gas-liquid chromatography can be used to analyse the components of car petrol.



A gas chromatograph

(a) **(i)** State an important property of the carrier gas.

.... **[1]**

(ii) What does the column consist of?

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.... **[2]**

(b) The first four components of a sample of petrol to emerge from the column are shown in **Table 1.1** in the order they come out.

1	methylbenzene
2	2-methylheptane
3	3-methylheptane
4	octane

Table 1.1

(i) Suggest the method used to identify these compounds as they emerge from the column.

.... **[1]**

(ii) Which of the compounds in **Table 1.1** has the shortest retention time?

.... **[1]**

(c) Suggest, with reasons, which of compounds 2, 3 and 4 from **Table 1.1** has the highest boiling point.

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.... **[3]**

(d) Octane can be cracked.

Write an equation for the cracking of octane into but-2-ene, $CH_3CH{=}CHCH_3$, and one other compound.

Use **molecular** formulae.

[1]

(e) Explain why but-2-ene has two stereoisomers.

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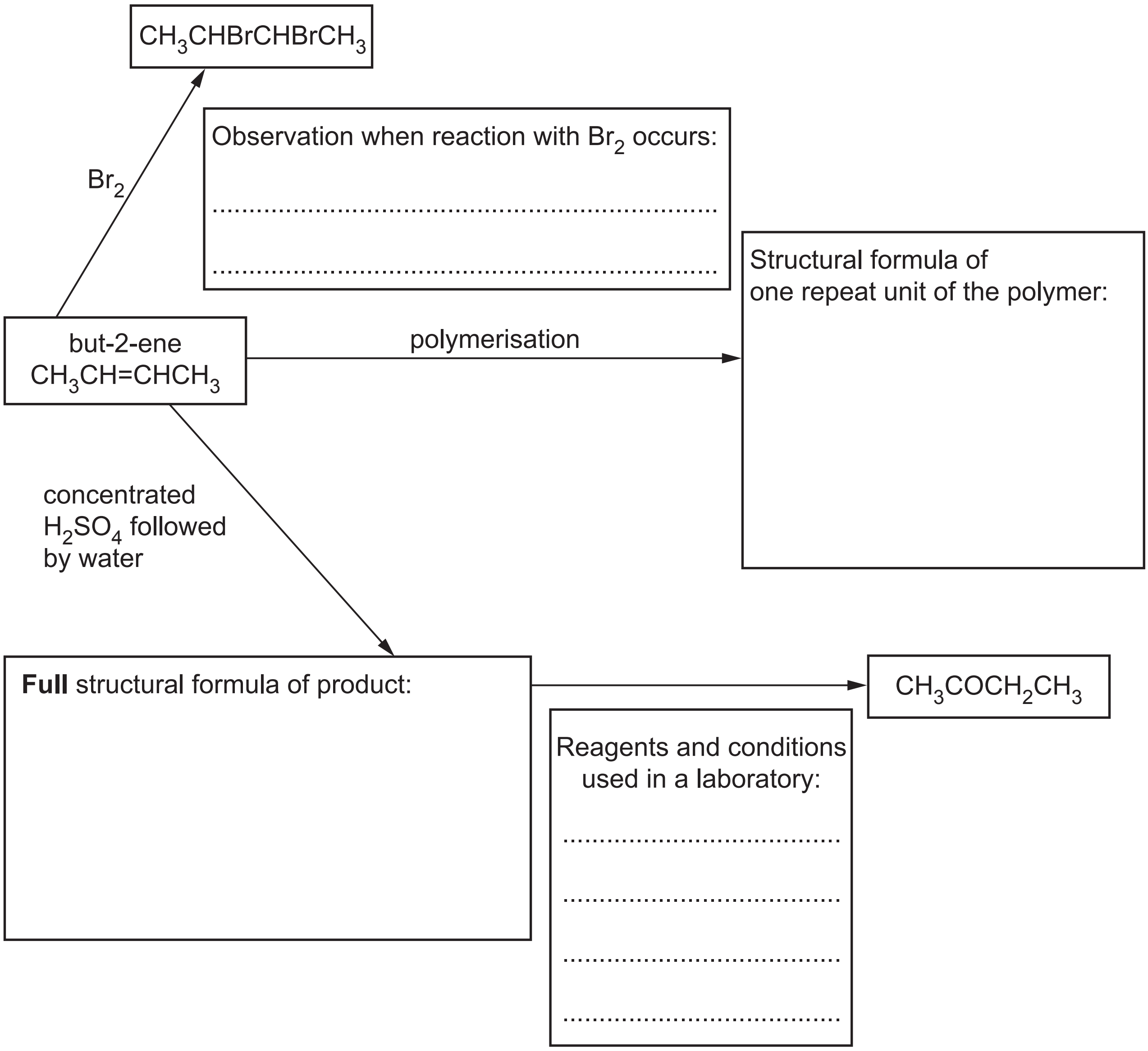
.... **[2]**

(f) Some reactions of but-2-ene are shown in the diagram below.

Complete the diagram by filling in the incomplete boxes.



[5]

(g) A hydrocarbon is completely burned.
11 g of carbon dioxide and 6.0 g of water are formed.

Calculate the empirical formula of the hydrocarbon.

formula .... **[3]**

2 Some students are investigating the rusting of iron.

They use the electrode potentials in **Table 2.1**.

	Half equation	$E^{\ominus}$ / V
1	$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	– 0.76
2	$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	– 0.44
3	.......$O_2(g) + H_2O(l)$ + ...$e^- \rightleftharpoons 2OH^-(aq)$	+ 0.40

Table 2.1

(a) (i) Complete half-equation 3 in **Table 2.1** by writing numbers on the dotted lines. **[2]**

(ii) Use oxidation states to state and explain what is being reduced in half-equation 3 in **Table 2.1**.

....

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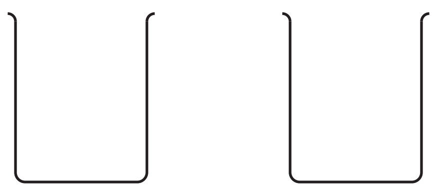
.... **[2]**

(b) The students set up a cell under standard conditions using half-equations 1 and 2 in **Table 2.1**. They aim to measure $E^{\ominus}_{cell}$.

(i) Complete the diagram of their apparatus.
Indicate how standard conditions are obtained.



[3]

(ii) Use the data in **Table 2.1** to calculate the $E^{\ominus}_{cell}$ value for the cell in **(b)(i)**.

$E^{\ominus}_{cell}$ = ... V **[1]**

(c) Zinc blocks are often fixed to the bottom of steel ships to stop the ships rusting in sea water.

A student compares this process with the cell in part **(b)(i)**.

The student makes the following statements:

- Electrons flow from the iron (steel) to the zinc.
- This stops the rusting by reversing half-equation 2.
- The process is limited as there is no salt bridge.

Comment, with reasons, on the student's statements.

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.... **[4]**

(d) The students add aqueous sodium hydroxide to a fresh aqueous solution of an iron(II) salt. A precipitate of iron(II) hydroxide forms that gradually turns to iron(III) hydroxide.

Write a full equation with state symbols for the formation of iron(III) hydroxide from iron(II) hydroxide.

[3]

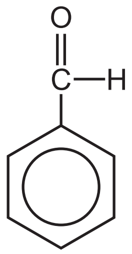
(e) The students are given a sample of 5.0 g of rust with the formula $Fe_2O_3{\bullet}2H_2O$.

The students heat the rust and find that it loses 1.0 g.

Show by calculation whether the students have the correct result.

[2]

3 Benzaldehyde gives the smell and taste of almonds to almond oil.



benzaldehyde

(a) The mass spectrum of benzaldehyde has many peaks.
Two of the peaks have *m* / *z* values of 107 and 77.

Suggest explanations for these values.

107 ....

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77 ....

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[2]

(b) Benzaldehyde has a benzene ring.
The benzene ring has delocalised electrons.

Describe how the delocalised electrons are arranged in the benzene structure.

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.... **[2]**

(c) Benzene and ethene each undergo electrophilic reactions.

State how these reactions differ.

....

.... **[1]**

(d) Benzaldehyde can be nitrated to give nitrobenzaldehyde, which is yellow.

(i) A student says the colour occurs because nitrobenzaldehyde absorbs the complementary colour to yellow and emits yellow light.

Comment on the student's statement.

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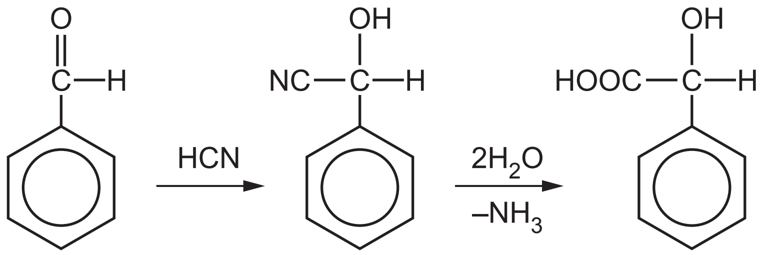
.... **[3]**

(ii) Calculate the wavelength (in cm) of the light associated with an electron energy change of 3.5×10^{-19} J.

wavelength = ... cm **[3]**

(e) Mandelic acid, an antibiotic, can be made from benzaldehyde.

The reaction scheme below shows a synthesis of mandelic acid.



benzaldehyde compound **C** mandelic acid

(i) Draw the mechanism for the attack of a cyanide ion on benzaldehyde, followed by attack by H^+ to give compound **C**.

[2]

(ii) Name the functional group attached to the benzene ring in compound **C**.

.... **[1]**

(iii) In an experiment, 5.0 g of benzaldehyde gives 6.3 g of mandelic acid.

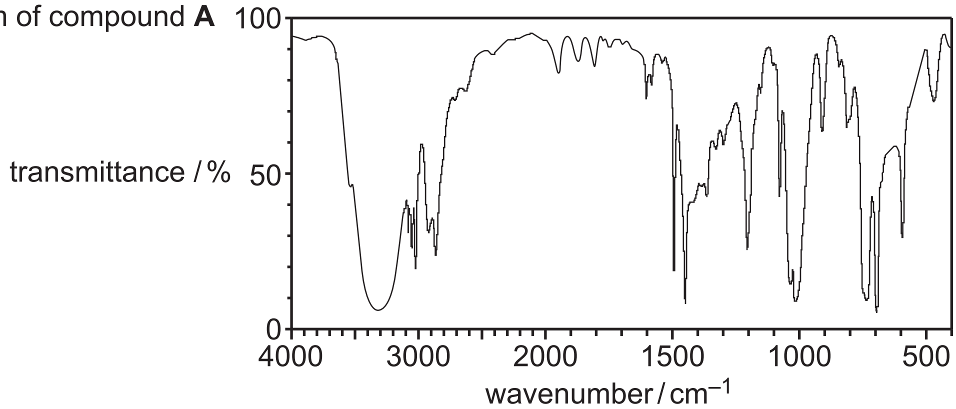
Calculate the percentage yield.

yield = ... % **[3]**

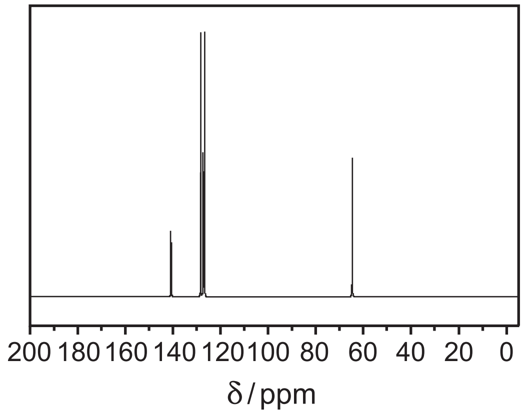
(f)* When benzaldehyde is reacted with alkali, and then neutralised, it forms two compounds, **A** and **B**.

Working may be done on this page but it will not be marked.

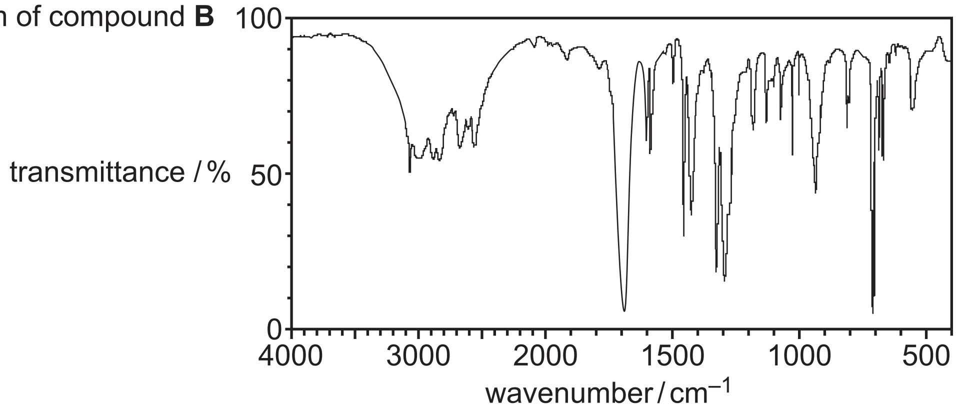
Infrared spectrum of compound **A**



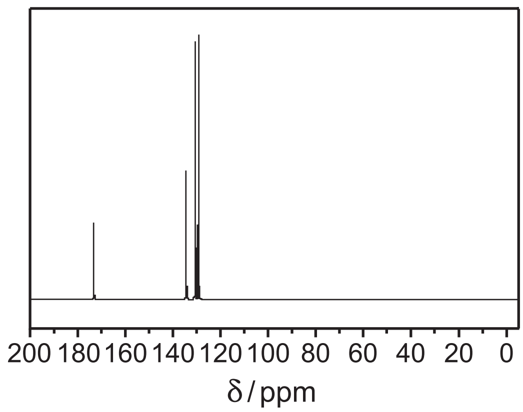
^{13}C – NMR spectrum of compound **A**



Infrared spectrum of compound **B**



^{13}C – NMR spectrum of compound **B**



Use the spectra on page 12 to identify compounds **A** and **B**. Each one has seven carbon atoms.
Give full evidence from **all** the spectra, including relevant wavenumbers and chemical shifts.

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Additional answer space if required.

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4 Some students investigate the dissolving of potassium salts.

(a) The students are given 10.1 g of potassium nitrate, KNO_3.
They dissolve this in 150 cm^3 of water.

The temperature goes down by 5.3 °C.

(i) Give practical details of how they would carry out the experiment.

Include the apparatus required and the measurements to be made.

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.... **[4]**

(ii) Use the students' result to calculate a value for $\Delta_{solution}H$ in kJ mol^{-1}.

Give your answer to an **appropriate** number of significant figures.

Assume the solution has the same specific heat capacity and density as water.

$\Delta_{solution}H$ = ... kJ mol^{-1} **[4]**

(b) The students find the data below for dissolving another salt, KIO_3, in water.

$\Delta_{solution}H = +17.8\,kJ\,mol^{-1}$

$\Delta_{sys}S = +41\,JK^{-1}mol^{-1}$

(i) Explain the sign of $\Delta_{sys}S$ in terms of the particles involved in the process.

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.... **[2]**

(ii) A student says that the dissolving of KIO_3 is not feasible below 434 K.

Carry out suitable calculations and comment on the student's statement.

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.... **[4]**

(c) The students then discuss the enthalpy and entropy data for the industrial process shown in **Equation 4.1**.

$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$ $\Delta H = +180\,kJ\,mol^{-1}$ **Equation 4.1**

(i) $\Delta_{sys}S$ is very small for the forward reaction.

Explain why, in terms of **Equation 4.1**.

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.... **[1]**

(ii)* A chemical company considers the conditions for making NO by the process shown in **Equation 4.1**.

Suggest and explain the conditions of temperature and pressure that you would recommend to the company for this process.

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Additional answer space if required.

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5 This question refers to the Advanced Notice Article 'Smartphones: Smart Chemistry' that is included as an insert with this paper.

(a) Lanthanide elements are important in smartphones.

The lanthanides can be described as being in a 'block' of the Periodic Table.

Use the electronic configurations of the lanthanides shown in the article to suggest the name of the block.

.... **[1]**

(b) The lanthanides were discovered using atomic emission spectroscopy.

(i) Describe the appearance of an atomic emission spectrum.

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.... **[1]**

(ii) Describe how emission spectra are formed and explain how they allow different elements to be distinguished.

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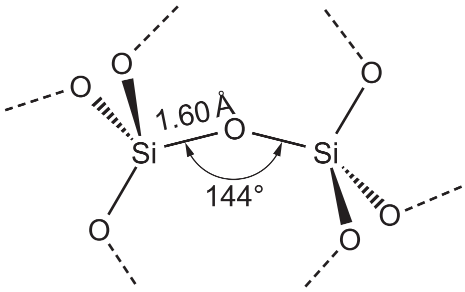
.... **[3]**

(c) The Article shows that the three-dimensional structure of silicon dioxide can be represented as shown below.



The Si-O-Si bonds have a larger angle than the H-O-H bond angle of water.

(i) State the H-O-H bond angle in a water molecule.

.... **[1]**

(ii) Explain the bond angle in water.

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.... **[3]**

(d) Ceramics and 'gorilla glass' are both strong in resisting compression.

Which features of their chemical structures do they share and what does gorilla glass have in addition?

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.... **[3]**

(e) Explain why potassium ions can replace sodium ions in the structure of 'gorilla glass' and why potassium ions are larger.

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.... **[2]**

(f) An aluminosilicate ion has the formula $Al_2Si_{14}O_{32}^{x-}$.

State and explain the value of *x* using oxidation states.

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.... **[2]**

(g) Indium tin oxide consists of indium oxide and tin oxide and is used in capacitive touchscreens. Indium forms the oxide In_2O_3.

(i) Predict the charge on the indium ion from its position in the Periodic Table.

Use this to explain the formula In_2O_3.

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.... **[2]**

(ii) The Article says that one form of indium tin oxide has percentages by mass: 53% In, 28% Sn and 19% O.

Show how the percentages by mass are related to the formulae of the oxides from which the indium tin oxide is made.

[2]

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).

Oxford Cambridge and RSA

Tuesday 12 October 2021 – Morning

A Level Chemistry B (Salters)

H433/02 Scientific literacy in chemistry

Advanced Notice Article

Time allowed: 2 hours 15 minutes

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INSTRUCTIONS

- Do **not** send this Advanced Notice Article for marking. Keep it in the centre or recycle it.

INFORMATION

- This is a clean copy of the Advance Notice Article you have already seen.
- This document has **8** pages.

Smartphones: Smart Chemistry

Adapted from an article by Brian Rohrig in the April/May 2015 ChemMatters online magazine of the American Chemical Society

Could you last a day without your cell phone? As many as 84% of U.S. residents could not, according to a recent poll conducted by *Time* magazine. It is hard to believe that 20 years ago, hardly anyone even owned a cell phone. And now the cell phone has morphed into something bigger and better – the smartphone. Worldwide, more than *one billion* smartphones were purchased last year. If you own a smartphone, you are probably aware that in a year or two, it will be practically obsolete, because the smartphone just keeps getting smarter.

In the 1950s, you would have needed a whole bank of computers on an entire floor of an office building to do what you are able to do with a single smartphone today. Even a low-end smartphone has more computing power than the computer system the National Aeronautics and Space Administration (NASA) used to put a man on the moon. Amazingly, you can surf the Internet, listen to music, and text your friends with something that fits in the palm of your hand. None of this would be possible without chemistry, and every time you use your smartphone, you are putting chemistry into action.

Smartphone chemistry

If you are wondering what chemistry has to do with smartphones, just look at the periodic table. Of the 83 stable (nonradioactive) elements, at least 70 of them can be found in smartphones! That's 84% of all stable elements.

Metals are what make smartphones so "smart." An average smartphone may contain up to 62 different metals. One rather obscure group of metals – the rare-earth metals – plays a vital role. These rare-earth metals include scandium and yttrium, as well as elements 57–71, known as the lanthanides, because they begin with the element lanthanum. The lanthanides often appear as the first of two free-floating rows located at the bottom of the periodic table. Scandium and yttrium are included because their chemical properties are similar to those of the lanthanides.

If you examine several varieties of smartphones, you can find 16 of the 17 rare earth metals. The only one you will not find is promethium, which is radioactive.

Many of the vivid red, blue, and green colours you see on your screen are due to rare-earth metals, which are also used in the phone circuitry and in the speakers. Also, your phone would not be able to vibrate without neodymium ($[Kr]4d^{10}4f^{4}5s^{2}5p^{6}5d^{0}6s^{2}$) and dysprosium ($[Kr]4d^{10}4f^{10}5s^{2}5p^{6}5d^{0}6s^{2}$).

Rare-earth metals are also used in many other high-tech devices. They are found in televisions, computers, lasers, missiles, camera lenses, fluorescent light bulbs, and catalytic convertors. Rare-earth elements are so important in the electronics, communications, and defence industries that the U.S. Department of Energy dubbed them the "technology metals."

Smartphone's display

The screen allows you to see the phone's display. If you have ever dropped your phone without damaging the screen, you were probably relieved. Smartphone screens are designed to be extremely tough.

This toughness is actually the result of a serendipitous accident. In 1952, a chemist at Corning Glass Works was trying to heat a sample of glass to 600 °C in a furnace when a faulty thermostat caused it to be heated to 900 °C. Upon opening the door, he was glad – and surprised – to find that his glass sample was not a melted pile of goo and that it had not ruined the furnace. When he took it out with tongs, he dropped it on the floor (another accident). But instead of breaking, it bounced!

Thus, was born the world's first synthetic glass-ceramic, a material that shares many properties with both glass and ceramic. Glass is an amorphous solid, because it lacks a crystalline structure (**Fig. 1(a)**). The structure is not ordered, but is arranged more like a liquid, yet frozen in place. Because glass does not contain planes of atoms that can slip past each other, there is no way to relieve stress. Excessive stress forms a crack, and bonds on the surface of the crack break. As the crack grows, the intensity of the stress increases, more bonds break, and the crack widens until the glass breaks.

Ceramics, on the other hand, tend to be regular and crystalline (**Fig. 1(b)**). When they form crystals, the strong force of attraction between the planes makes it difficult for one plane to slip past another. Ceramics are therefore brittle. They resist compression, but they can break when they are bent. The attraction between planes can be increased by the introduction of ions into the structure.

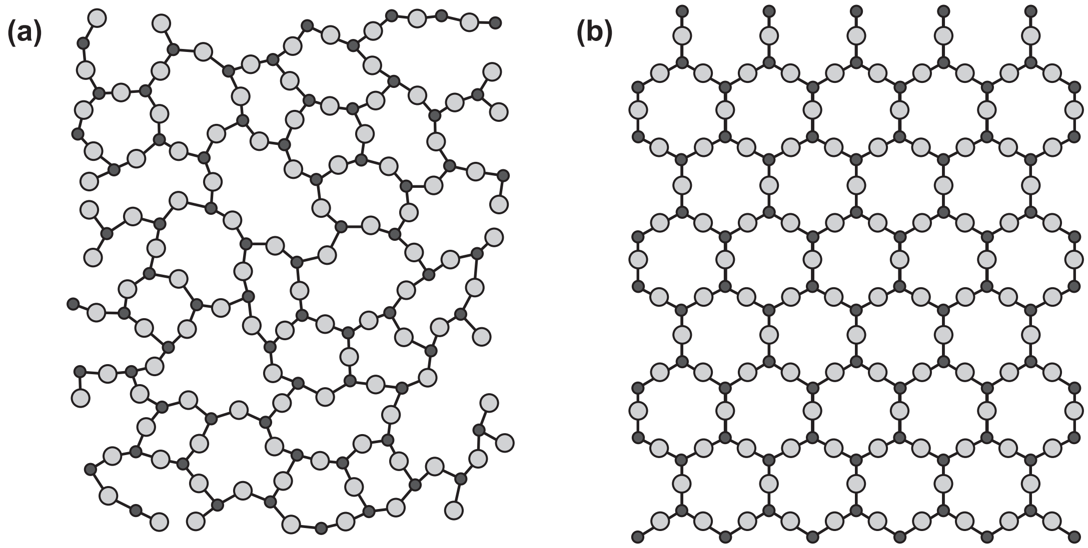

Fig. 1

Two dimensional comparison of the chemical structures of **(a)** an amorphous solid made of silicon dioxide (glass) and **(b)** a crystal of silicon dioxide (ceramic)

In three dimensions, the structures can be represented as in **Fig. 2**:

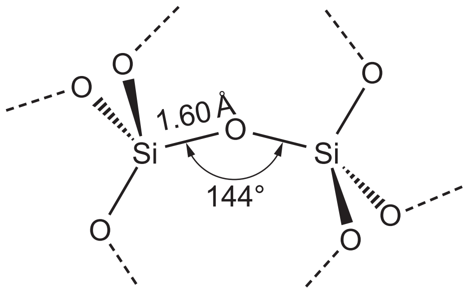

Fig. 2

The combination of glass and ceramic forms a material that is tougher and stronger than each of the materials by themselves. A glass-ceramic is formed by overheating the glass, so a portion of its structure is transformed into a fine-grained crystalline material. Glass-ceramics are at least 50% crystalline, and in some cases, they are more than 95% crystalline.

This amazing glass-ceramic material is so resistant to heat that it has been used in the nose cones of supersonic-guided missiles used by the military. As a result of the success of glass-ceramic materials, the Corning Glass Works Company undertook a large research effort to find ways to make ordinary transparent glass as strong as glass-ceramic products. By 1962, Corning had developed a very strong type of chemically strengthened glass, unlike anything ever seen before. This super-strong glass would eventually make its way to nearly every smartphone screen. It is so strong it goes by the name, **Gorilla Glass**. **Laboratory tests have shown that Gorilla Glass can withstand 100,000 pounds of pressure per square inch!**

Gorilla Glass is composed of oxygen, silicon and aluminium—also called aluminosilicate glass—along with sodium ions (**Fig. 3**).

But Gorilla Glass gains its tremendous strength through one final step, in which the glass is chemically strengthened. The glass is put into a molten bath of potassium salt, usually potassium nitrate, at 300 °C. Potassium ions replace sodium ions in the structure and take up more space in the glass than do sodium ions. The anions are aluminosilicate.

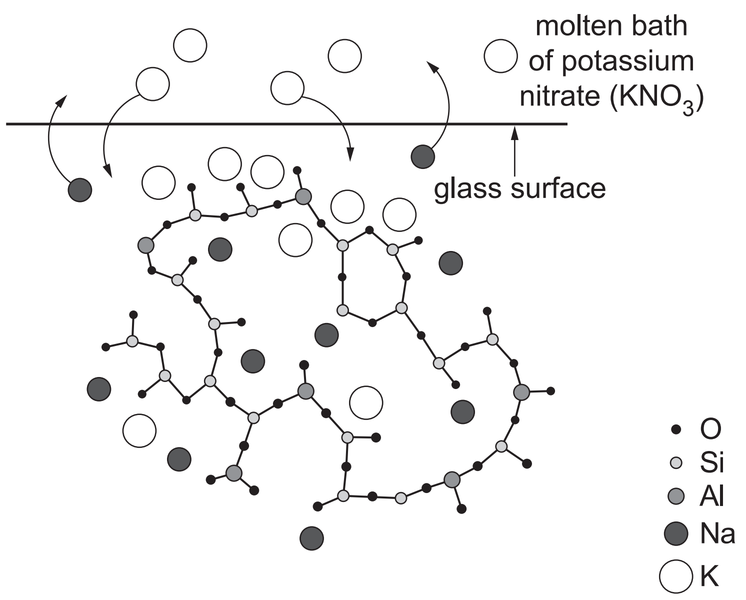

Fig. 3

Cramming larger ions into the spaces formerly occupied by smaller ions results in a compressing of the glass. Compressed glass is very strong. As a result of this compression, a lot of elastic potential energy is stored in the glass, much like the elastic potential energy that you might find in a compressed spring.

What's behind a touchscreen?
As every smartphone user knows, the screen on a smartphone is far more than just a tough piece of glass. It is a screen that responds to your touch—aptly named a touchscreen—giving you a personal connection to your phone.

There are two basic categories of touchscreens. The first category of touchscreens, called **resistive touchscreens**, can be touched with any type of material and they will still work. You can activate the screen even if wearing gloves. Resistive touchscreens are used when you sign for a delivery on a display screen.

Resistive touchscreens are composed of two thin layers of conductive material under the surface. When you press down a resistive touchscreen, it physically indents, causing the two layers to touch, completing the circuit and changing the electrical current at the point of contact. The software recognizes a change in the current at these coordinates and carries out the action that corresponds with that spot. Resistive touchscreens are also known as pressure-sensitive screens.

Smartphones use the second basic category of touchscreens, called **capacitive touchscreens** which are electrical in nature. A capacitor is any device that stores electricity.

When a finger presses down on a capacitive touchscreen, a very small electrical charge is transferred to the finger, creating a voltage drop on that point of the screen. A controller within the smartphone processes the location of this voltage drop and orders the appropriate action.

Glass, being an insulator, does not conduct electricity. Even though the glass contains ions, they are locked into place, stopping electricity from flowing through. So, the glass screen must be coated with a thin transparent layer of a conductive substance, usually indium tin oxide, which is laid out in crisscrossing thin strips to form a grid pattern. One form of indium tin oxide has percentages by mass: 53% In, 28% Sn and 19% O.

This conductive grid acts as a capacitor, storing very small electrical charges. When you touch the screen, a tiny bit of this stored electrical charge enters your finger—not enough for you to feel but enough for the screen to detect. As this electrical charge leaves the screen and enters your finger, the screen registers a voltage drop, the location of which is processed by the software, which orders the resulting action.

This tiny bit of electrical current enters your finger because your skin is an electrical conductor—primarily due to the combination of salt and moisture on your fingertips, creating an ionic solution. Your body actually becomes part of the circuit, as a tiny bit of electricity flows through you every time you use the touchscreen on your phone.

Smartphone technology is evolving at a dizzying pace. You can now use your smartphone to check your blood sugar, adjust your home's thermostat, and start your car. Twenty years ago, no one envisioned that people would someday take more pictures with their cell phones than with their stand-alone cameras. It is anyone's guess what will come next. Thanks to the intersection of chemistry and innovation, the possibilities are limitless.

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