Coimisiún na Scrúduithe Stáit
State Examinations Commission

LEAVING CERTIFICATE EXAMINATION, 2021

PHYSICS AND CHEMISTRY – HIGHER LEVEL

WEDNESDAY, 23 JUNE – MORNING, 9:30 to 12:30

Five questions to be answered.

Answer any **two** questions from Section I, any **two** questions from Section II and **one** other question from either Section I or Section II.

All the questions carry equal marks.

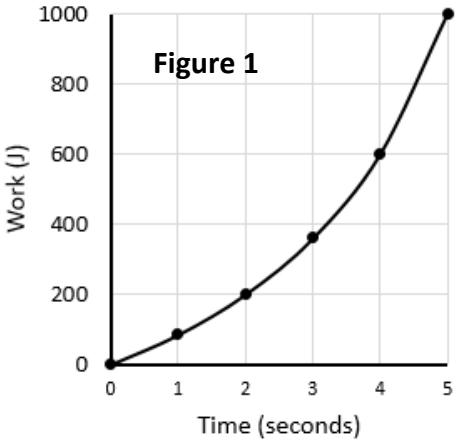
N.B. Relevant data are listed in the *Formulae and Tables* booklet, which is available from the superintendent. Take $g = 9.8$ m s^{-2} as the acceleration due to gravity at the surface of the Earth.

SECTION I – PHYSICS

1. Answer **eleven** of the following items (*a*), (*b*), (*c*), etc. All the items carry equal marks.
Keep your answers short.

(*a*) Identify the scalar quantities in the following:
mass velocity force energy time

(*b*) **Figure 1** is a work-time graph.
Find the average power developed over the 5 s.
Is power constant in this case?



(*c*) State the *principle of conservation of momentum*.

(*d*) The blink of an astronaut's eye lasts 0.11 s.
How far does light travel in space in that time?

(*e*) What is meant by the triple point of water?

(*f*) Sketch the graph obtained when the volume of a fixed mass of gas at constant pressure is plotted against its temperature in °C.

(*g*) State the thermometric property used in each of the following:
(*i*) a liquid-in-glass thermometer,
(*ii*) a constant-volume gas thermometer.

(*h*) Give two characteristics of a good thermometer.

(*i*) State Snell's law.

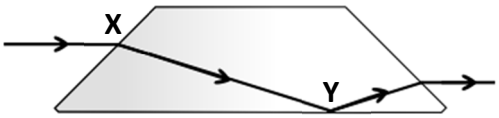


Figure 2

(*j*) Identify the phenomenon occurring (*i*) at **X**, (*ii*) at **Y**,
in **Figure 2** as a ray of light travelling in air strikes and travels through the prism.

(*k*) Name a phenomenon which can be explained only by reference to
(*i*) the wave nature of light, (*ii*) the properties of photons of light.

(*l*) ***F*** is the force between two identical point charges a certain distance apart. When the distance between them is doubled, what is the new force between them in terms of ***F***?

(*m*) The electrical field pattern in **Figure 3** is produced when two charges $\mathbf{Q}_1$ and $\mathbf{Q}_2$ are placed close together.
What type of charge, positive or negative, is (*i*) $\mathbf{Q}_1$ (*ii*) $\mathbf{Q}_2$?

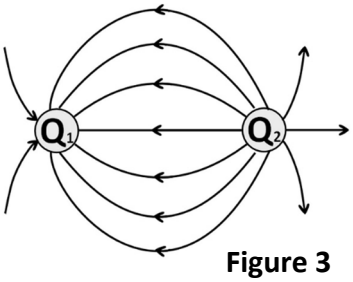


Figure 3

(*n*) Calculate the charge, in μC, transferred when a 0.6 μF parallel-plate capacitor is connected to a 6 V power supply.

(*o*) What is electromagnetic induction?

(*p*) Assuming no power loss during operation of a step-up transformer, how do
(*i*) the sizes of the output and the input voltages compare,
(*ii*) the sizes of the output and the input currents compare?

(*q*) In terms of sub-atomic particles what, is (*i*) an alpha-particle, (*ii*) a beta-particle?

(*r*) What is the half-life of a radioactive isotope whose activity decreases to $1/16^{th}$ of its original value in 32 hours? (11 × 6)

2. (*a*) (*i*) State Newton's second law of motion.

(*ii*) Derive the relationship *force* = *mass* × *acceleration* from this law. (15)

(*b*) (*i*) Draw a labelled diagram of an arrangement of apparatus used to verify that the acceleration of a fixed mass is proportional to the force applied.

(*ii*) How is the mass being accelerated kept constant?

(*iii*) What measurements are recorded? (24)

(*c*) A small object dropped from a height on a construction site could cause severe injury if it struck a person on the ground. See **Figure 4**.

Figure 4

The graph in **Figure 5** shows how the magnitude of the vertical momentum of an object of mass *m* varied with time over the first few seconds of its fall from a height, starting from rest, when the only force acting on it was gravitational.

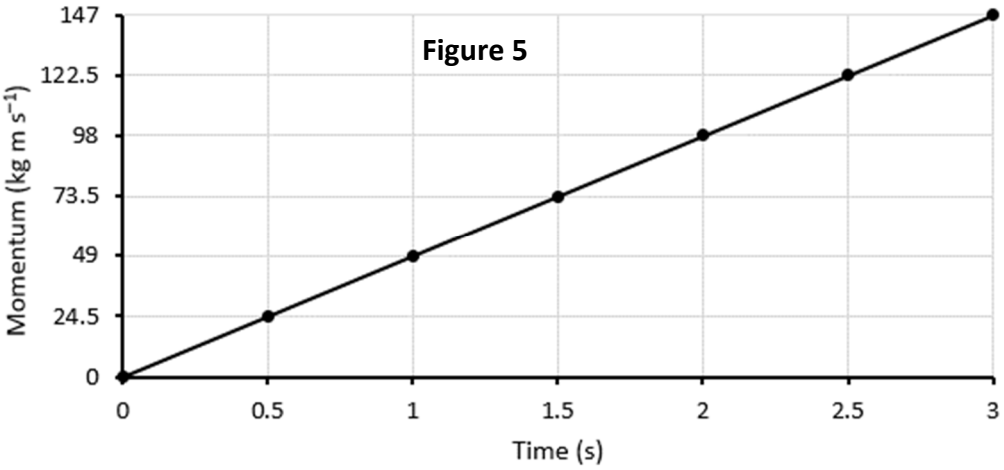


Figure 5

(*i*) After the first 3.0 s the object had a vertical speed of 29.4 m s^{-1}.
Use the graph to find *m*.

(*ii*) What quantity is determined by the slope of the graph?

(*iii*) Calculate the slope of the graph.

(*iv*) How far did the object fall in the first 3.0 s?

(*v*) Explain how the graph is consistent with Newton's second law. (27)

3. (*a*) (*i*) State the laws of reflection of light.

(*ii*) Describe an experiment to find the position of the image of an object formed by a plane mirror. (18)

(*b*) Draw a ray diagram to show image formation in a convex mirror. (6)

(*c*) An object was placed 9 cm in front of a plane mirror, a convex mirror and a concave mirror, in turn. A virtual image was formed in each case.

(*i*) Explain the underlined term.

(*ii*) How far was the image formed behind the plane mirror?

(*iii*) Find the focal length of the convex mirror if the image distance in the case of the convex mirror was 3 cm less than the image distance in the case of the plane mirror.

(*iv*) Find the image distance in the case of the concave mirror when its focal length was equal in magnitude to the focal length of the convex mirror.

(*v*) What was the magnification in each one of the three cases of reflection? (30)

(*d*) Convex mirrors are frequently used as rear-view mirrors in motor vehicles. State (*i*) an advantage, (*ii*) a disadvantage, of using convex mirrors instead of plane mirrors for this purpose.

(*iii*) Give one use of a concave mirror and state why it is suitable for this use. (12)

4. (*a*) (*i*) What is the *ideal gas*?

(*ii*) How is the kinetic theory used to explain how a gas exerts pressure?

(*iii*) Under what conditions do real gases behave most like the ideal gas? (15)

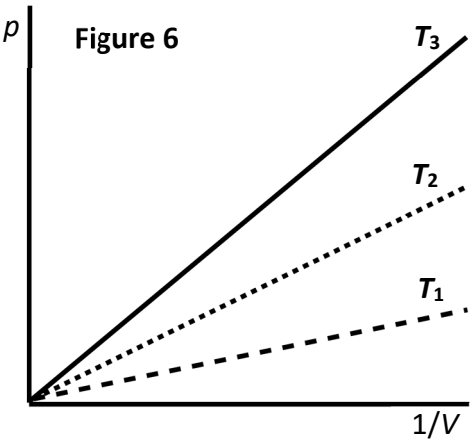
(*b*) What is the effect of increasing the pressure of a sample of gas at constant temperature on

(*i*) the average kinetic energy of the molecules of the gas,

(*ii*) the volume of the gas?

Explain your answer in each case. (12)

Figure 6



(*c*) The graph in **Figure 6** shows how the pressure of a fixed mass of gas varies with the inverse of its volume at three different temperatures.

(*i*) Name and state the law verified in **Figure 6**.

(*ii*) Draw a labelled diagram of an apparatus suitable for use in verifying this law.

(*iii*) Describe how the measurements used to draw the graph were obtained.

(*iv*) Which is the lowest temperature, T_1, T_2 or T_3? Justify your answer. (30)

(*d*) Chlorine gas is widely used to purify drinking water supplies. A sample of chlorine gas occupies 8.7 litres at a pressure of 1.19×10^5 Pa and a temperature of 24 °C. Calculate the temperature at which this sample of chlorine gas occupies a volume of 10.2 litres at a pressure of 1.13×10^5 Pa. (9)

5. (*a*) Define electric current. (6)

(*b*) In an experiment to investigate the heating effect of an electric current, a student first measured the changes in temperature $\Delta\theta$ when the same current passed through heating coils of different resistances *R* (immersed in a fixed mass of water in identical containers for the same time). The following data were recorded.

R (Ω)	0	2.0	4.0	5.0	6.0	7.5	8.0
$\Delta\theta$ (^{o}C)	0	2.9	5.6	7.0	8.4	10.6	11.4

(*i*) Plot a graph of $\Delta\theta$ *versus R* (*x*-axis).

(*ii*) Use the graph to predict the temperature rise when $R = 3.5\ \Omega$.

(*iii*) What relationship between temperature rise and resistance is shown by your graph? (18)

(*c*) The student then measured the changes in temperature $\Delta\theta$ when different currents *I* were passed through the same heating coil (immersed in a fixed mass of water in identical containers for the same time). The following data were recorded.

I (A)	0	0.5	1.0	1.25	1.5	1.75	2.0
$\Delta\theta$ (^{o}C)	0	0.7	2.9	4.6	6.6	9.1	11.8

(*i*) Plot a graph of $\Delta\theta$ *versus* I^2 (*x*-axis).

(*ii*) Use the graph to predict the current associated with a temperature rise of 8.8 °C.

(*iii*) What relationship is shown by your graph? (21)

(*d*) **Figure 7** represents a current-carrying wire passing through a square of cardboard. Copy the diagram into your answerbook and complete it to show the magnetic field associated with the current *I* in the wire. (6)

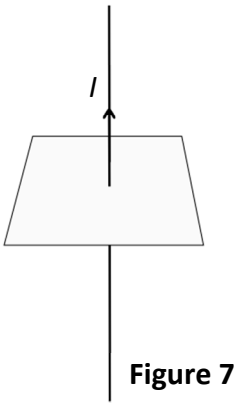


Figure 7

(*e*) **Figure 8** shows a metal wheel which rotates anticlockwise when the switch is closed.

(*i*) What principle is demonstrated by this arrangement?

Suggest how you could make the wheel

(*ii*) rotate faster,

(*iii*) rotate clockwise.

(*iv*) Give an example of an appliance based on the principle demonstrated by this arrangement. (15)

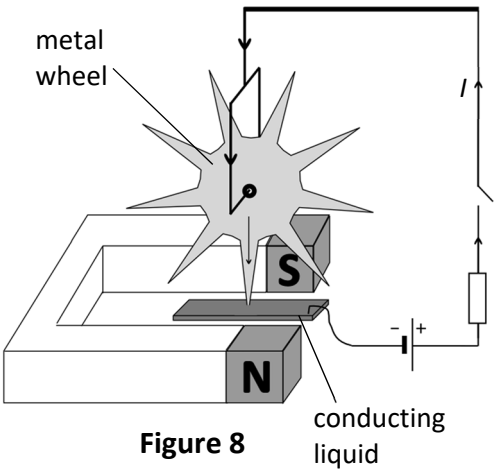


Figure 8

6. Answer any **two** of the following parts (*a*), (*b*), (*c*), (*d*). Each part carries 33 marks.

(*a*) Define the S.I. unit of energy, i.e. the joule.
Distinguish between potential energy and kinetic energy. (12)

Space shuttles were designed to be launched vertically, orbit the Earth in space carrying out various missions, re-enter the Earth's atmosphere and land on runways like gliders.

(*i*) How much potential energy was required to raise a space shuttle of mass 1.03×10^5 kg to a height of 110 m above the launch pad?

(*ii*) After launch, a shuttle docked with the international space station and together they orbited Earth at a distance of 6.78×10^3 km from the centre of the Earth. Find the gravitational force on the shuttle and space station if their combined mass was 5.10×10^5 kg and the mass of the Earth is 5.97×10^{24} kg.

(*iii*) A shuttle and its contents of combined mass 9.04×10^4 kg returned to the surface of the Earth after a mission with a horizontal touchdown velocity of 105 m s^{-1}. How much energy was converted into other forms, e.g. heat, sound, etc, to bring the shuttle to rest after touchdown on a horizontal runway? (21)

(*b*) State Ohm's law. (6)
The circuit in **Figure 9** contains four identical 5 Ω bulbs **W**, **X**, **Y** and **Z** and a 9 V battery. Find
(*i*) the total resistance of this arrangement of bulbs,
(*ii*) the current flowing in each bulb.
Describe what would be observed
(*iii*) if bulb **Y** blew,
(*iv*) if bulb **X** blew. (27)

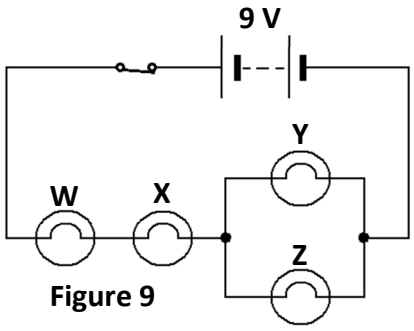


Figure 9

(*c*) **Figure 10** represents the electromagnetic spectrum. This is a series of different types of radiation, arranged in order of frequency, that have certain common characteristics, including their speed in a vacuum.

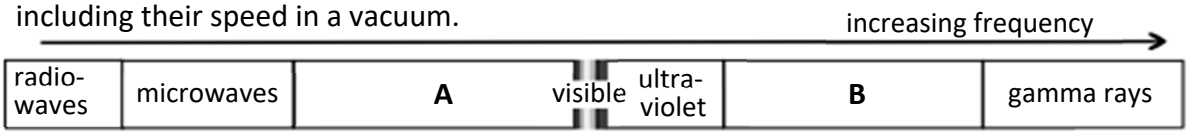


Figure 10

(*i*) Identify the type of radiation in each of the regions **A** and **B** of the spectrum.
(*ii*) Give an application for each of the radiations in regions **A** and **B**.
(*iii*) How can the radiation from region **A** be detected? (15)
(*iv*) Electromagnetic waves are <u>transverse</u> waves that can undergo <u>diffraction</u> and interference. Explain the underlined terms.
(*v*) Find the wavelength associated with an FM radio wave of frequency 88.2 MHz. (18)

(*d*) Consider the nuclear reaction: $\mathbf{{}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{144}_{56}Ba + {}^{89}_{w}Kr + x\,{}^{1}_{0}n + energy}$.
What type of nuclear reaction is involved?
What are the values of $\boldsymbol{w}$ and $\boldsymbol{x}$ in the equation above?
How could this reaction result in a chain reaction occurring in a sample of uranium–235? (15)

Consider the nuclear reaction: $\mathbf{{}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{b}_{a}Y + 2\,{}^{1}_{1}H + energy}$.
What type of nuclear reaction is involved?
Identify the element $\mathbf{Y}$ and the values of $\boldsymbol{a}$ and $\boldsymbol{b}$.
Why is this type of nuclear reaction only possible under extreme conditions? (18)

SECTION II – CHEMISTRY

7. Answer **eleven** of the following items (*a*), (*b*), (*c*), etc. All the items carry equal marks. *Keep your answers short*.

(*a*) How many (*i*) neutrons, (*ii*) electrons, does a $^{48}_{22}\mathbf{Ti}^{2+}$ ion have?

(*b*) **Figure 11** represents an electron transition from one energy level (E_3) to another (E_2) in an excited hydrogen atom. What coloured line in the hydrogen emission spectrum is associated with this specific transition?

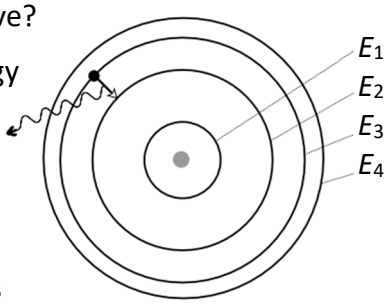


Figure 11

(*c*) (*i*) What is an anion?

(*ii*) Identify a group in the periodic table of the elements whose atoms are likely to form anions when bonding.

(*d*) Does a water molecule have an overall dipole moment? Explain your answer.

(*e*) How many atoms are there in 3.36 litres of carbon dioxide gas measured at s.t.p.?

(*f*) Ice and dry-ice are examples of molecular crystals. What are the forces between

(*i*) the water molecules in ice,

(*ii*) the carbon dioxide molecules in dry-ice?

(*g*) What are allotropes of an element?

(*h*) Explain why metallic crystals are good conductors of electricity.

(*i*) Write a balanced equation for the reaction of iron(III) oxide with carbon monoxide forming iron metal and carbon dioxide.

(*j*) What is a catalyst in a chemical reaction?

(*k*) State two characteristic properties of transition elements.

(*l*) What is meant by an amphoteric oxide? Give an example.

(*m*) Define heat of solution.


Figure 12

(*n*) Burette stopcocks like that shown in **Figure 12** are often made of Teflon, a polymer with the formula $\mathbf{(C_2F_4)}_{\boldsymbol{n}}$ where ***n*** is a large number. Calculate the percentage of fluorine by mass in Teflon. [**C** = 12; **F** = 19]

(*o*) A bromine solution, in a test-tube wrapped in aluminium foil to keep out the light, was decolourised when a gaseous hydrocarbon was bubbled through it. What conclusion may be drawn about the hydrocarbon?

(*p*) Which of the following compounds would you expect to have the strongest carbon to carbon bonding: ethane, ethene, ethyne, benzene?

(*q*) Show that propanal and propanone are structural isomers, i.e. they have the same molecular formula ($\mathbf{C_3H_6O}$) but different structural formulae.

(*r*) Identify the aromatic compounds shown in **Figure 13**.

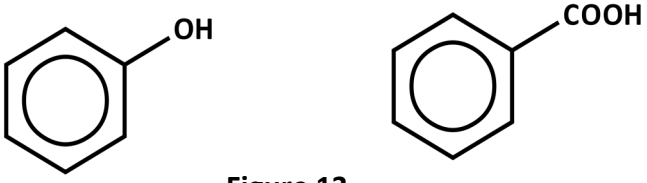


Figure 13

(11 × 6)

8. An electron in an atom is associated with an orbital, a sublevel, and a main energy level.

(*a*) (*i*) Define an atomic orbital.

(*ii*) Write the *s*, *p* electron configuration for aluminium.

How do the following orbitals in an atom of aluminium differ:

(*iii*) the 2*s* and the 3*s* orbitals,

(*iv*) the 2*s* and the $2p_x$ orbitals,

(*v*) the $2p_x$ and the $2p_y$ orbitals? (30)

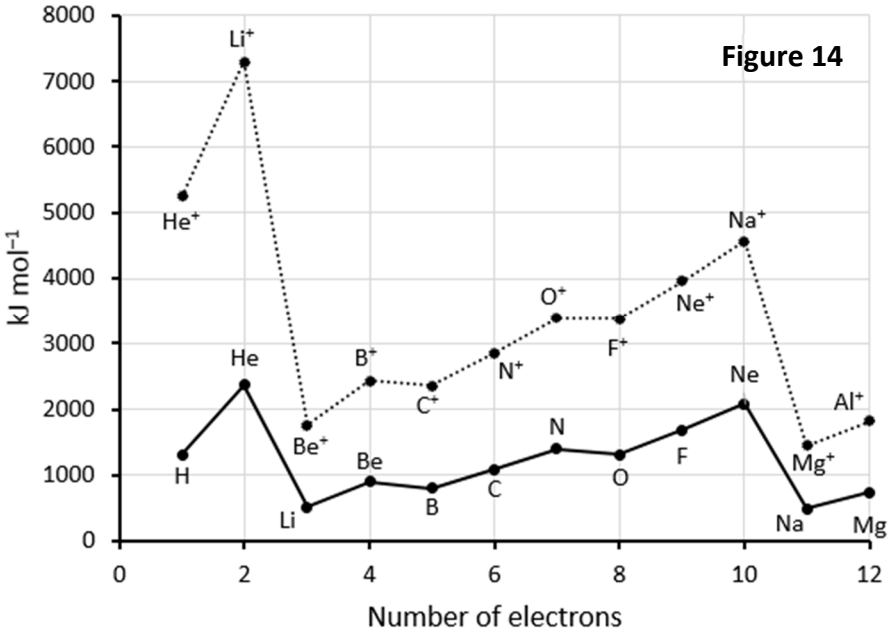
(*b*) (*i*) Define the first ionisation energy of an element.

(*ii*) The *second* ionisation of sodium is represented by the equation:

$$\mathbf{Na^+}_{(g)} \rightarrow \mathbf{Na^{2+}}_{(g)} + \mathbf{e^-}$$

Write a similar equation to represent the *first* ionisation of boron (**B**).

Figure 14 shows the first ionisation energy values for the elements hydrogen to magnesium and the second ionisation energy values for helium to aluminium.



(*iii*) Account for the high first ionisation energy value of helium compared to the other elements.

(*iv*) Explain the general increase in first ionisation energies from lithium to neon shown in the graph *and* the first ionisation energy peaks that occur at beryllium and nitrogen.

(*v*) Why is the second ionisation energy of lithium so high? (36)

9. (*a*) Define, according to Brønsted-Lowry theory, (*i*) an acid, (*ii*) an acid-base conjugate pair.

(*iii*) Distinguish between a weak acid and a strong acid.

(*iv*) Carbonic acid (**H_2CO_3**) is a weak acid formed when carbon dioxide dissolves in water.
What is the conjugate base of carbonic acid?

(*v*) Define pH.

(*vi*) Calculate the pH of a 0.08 M **NaOH** solution, correct to one decimal place.

(*vii*) Fizzy drinks allowed to stand open to the air gradually go 'flat', i.e. they lose dissolved **CO_2**.
Would you expect the pH of a fizzy drink to increase or decrease as it goes flat? (30)

(*b*) Many fizzy drinks contain citric acid (**$C_6H_8O_7$**), a weak tribasic acid, as a flavouring. To determine the concentration of citric acid in a colourless fizzy drink, that had been allowed to go flat, 25.0 cm^3 portions of the drink were titrated with a *standard solution* of 0.08 M sodium hydroxide in the presence of phenolphthalein indicator.

Taking **$R(COOH)_3$** to represent the tribasic citric acid, the balanced equation for the reaction can be given as:

$$R(COOH)_3 + 3NaOH \rightarrow R(COONa)_3 + 3H_2O$$

A pipette like that shown in **Figure 15** was used to measure a 25.0 cm^3 portion of the flat fizzy drink into a conical flask for each titration.

Figure 15

How should (*i*) the pipette, (*ii*) the conical flask, have been prepared for use?

(*iii*) What determined the number of 25.0 cm^3 portions of flat fizzy drink that needed to be measured out and titrated? (15)

(*c*) The standard solution of sodium hydroxide was added from a burette.

(*i*) Explain the underlined term.

(*ii*) What colour change was observed at the end point in the conical flask using phenolphthalein indicator? (9)

(*d*) On average, 13.3 cm^3 of 0.08 M **NaOH** were required to neutralise 25.0 cm^3 of citric acid solution according to the balanced equation above.

Calculate the concentration of citric acid (**$C_6H_8O_7$**) in the fizzy drink

(*i*) in moles per litre,

(*ii*) in grams per litre. (12)

10. Corrosion of a metal involves <u>oxidation</u> of the metal. Extraction of a metal from its ore involves <u>reduction</u> of a compound of the metal.

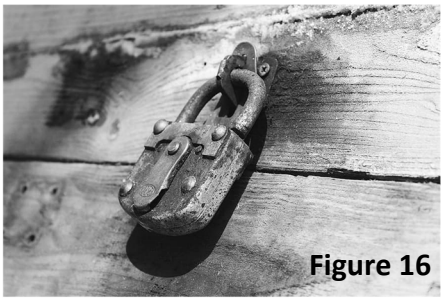


Figure 16

(*a*) (*i*) Define the underlined terms.

(*ii*) Identify the substance acting as the reducing agent in the following reaction.

$Al_2O_3 + 3H_2 \rightarrow 2Al + 3H_2O$ (12)

(*b*) (*i*) What is the list of elements given in order of decreasing ease of oxidation called?

(*ii*) Arrange the following elements in order of decreasing ease of oxidation: **Al**, **Pb**, **Ag**, **Mg**, **Na**, **Fe** and **hydrogen**.

(*iii*) **Figure 16** shows a rusting padlock. Explain why iron is observed to corrode more rapidly than aluminium.

(*iv*) Describe **two** ways, involving chemical reactions, of preventing corrosion. (27)

(*c*) Magnesium is extracted by the <u>electrolysis</u> of molten $MgCl_2$ using <u>inert electrodes</u>.

(*i*) Explain the underlined terms.

(*ii*) Write balanced equations for the reactions that occur at the cathode and the anode during this electrolysis.

(*iii*) When 4.8 kg of magnesium were produced in this way, what charge passed through the electrolyte? (27)

11. Recently many manufacturers of fuel ethanol and beverage ethanol switched production to sanitisers consisting of aqueous ethanol solutions with about 70% ethanol. See **Figure 17**.


Figure 17

(*a*) (*i*) Describe the appearance of ethanol.

(*ii*) Identify the functional group of the ethanol molecule *and* explain why ethanol is very soluble in water.

(*iii*) To what homologous series does ethanol belong? (18)

Figure 18 shows some reactions of ethanol.

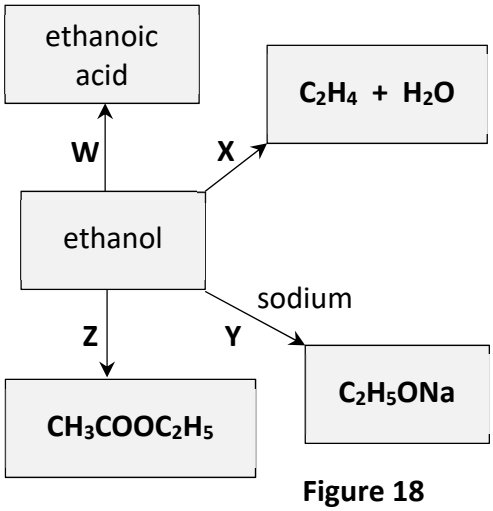


Figure 18

(*b*) (*i*) Name the type of reaction occurring in each of **W**, **X** and **Z**.

(*ii*) Identify a suitable reagent for reaction **W**.

(*iii*) Give the IUPAC name for the organic product of reaction **Z**.

(*iv*) What property of ethanol is demonstrated in reaction **Y**?

(*v*) Identify the chemical required to bring about reaction **X** *and* describe its appearance.

(*vi*) Draw a labelled diagram of the arrangement of apparatus used to carry out reaction **X** and collect a sample of C_2H_4.

(*vii*) State a safety precaution taken during this preparation. (48)

12. Answer any **three** of the following parts (*a*), (*b*), (*c*), (*d*). Each part carries 22 marks.

(*a*) AdBlue, a solution of urea ($\mathbf{NH_2CONH_2}$) in water, is an additive used to remove oxides of nitrogen from the exhaust gases of diesel-fuelled engines. See **Figure 19**.

When AdBlue is injected into the hot exhaust stream the following reaction occurs producing ammonia:

$$\mathbf{NH_2CONH_2 + H_2O \rightarrow 2NH_3 + CO_2}$$

This ammonia reacts simultaneously with nitrogen(II) oxide and nitrogen(IV) oxide in the exhaust stream according to the following balanced equations:

$$\mathbf{4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O}$$

$$\mathbf{6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O}$$

Figure 19

(*i*) How many moles of ammonia were obtained from the decomposition of all 1620 g urea in a container of AdBlue?

(*ii*) When one such container of AdBlue was used up, 4 moles of $\mathbf{O_2}$ had reacted with **NO** in the exhaust stream. How many moles of $\mathbf{NO_2}$ could have been removed at the same time by the remaining $\mathbf{NH_3}$?

(*iii*) How many water molecules were produced as a result of removing the **NO**?

(*iv*) What environmental problem is caused by excess oxides of nitrogen in air?

(*b*) Define (*i*) atomic number, (*ii*) atomic mass, (*iii*) relative atomic mass.

Silicon has three naturally occurring stable isotopes with mass numbers 28, 29 and 30. Silicon–28 occurs with 92.2% abundance, silicon–29 with 4.7 % abundance and silicon–30 with 3.1% abundance. Only traces of other radioactive isotopes exist.

Use this data to calculate the relative atomic mass of silicon, correct to two decimal places.

(*c*) Define electronegativity.

Describe how electronegativity values can be used to predict the type of bond that occurs between a pair of atoms.

Draw a dot and cross diagram to show the bonding in a molecule of $\mathbf{BF_3}$.

Predict (*i*) the shape, (*ii*) the bond angle, in a $\mathbf{BF_3}$ molecule.

(*d*) State Hess's law.

Define heat of formation.

$\mathbf{C_xH_{2x}}$ is a gaseous fuel that burns completely in oxygen according to the following balanced equation.

$$\mathbf{C_xH_{2x}}_{(g)} + \frac{3x}{2}\mathbf{O_2}_{(g)} \rightarrow x\mathbf{CO_2}_{(g)} + x\mathbf{H_2O}_{(l)} \qquad \Delta H = -1412 \text{ kJ}$$

Use Hess's law and the following information to deduce the value of x in the formula $\mathbf{C_xH_{2x}}$.

$$x\mathbf{C}_{(s)} + x\mathbf{H_2}_{(g)} \rightarrow \mathbf{C_xH_{2x}}_{(g)} \qquad \Delta H = 52 \text{ kJ}$$

$$\mathbf{H_2}_{(g)} + \tfrac{1}{2}\mathbf{O_2}_{(g)} \rightarrow \mathbf{H_2O}_{(l)} \qquad \Delta H = -286 \text{ kJ}$$

$$\mathbf{C}_{(s)} + \mathbf{O_2}_{(g)} \rightarrow \mathbf{CO_2}_{(g)} \qquad \Delta H = -394 \text{ kJ}$$

Image Q10 on page 10: from www.piklist.com/free-photos-shqex,
File: castle-padlock-metal-capping-secure-rust-wooden-door-protect-shut-off.jpg,
accessed 26 August 2020

Image Q12(*a*) on page 11: from www.flickr.com
File: photos/opelblog/41946956472, accessed 15 June 2020, CC-BY-NC-ND-2.0

Leaving Certificate – Higher Level

Physics and Chemistry

Wednesday, 23 June
Morning, 9:30 – 12:30