Coimisiún na Scrúduithe Stáit
State Examinations Commission

LEAVING CERTIFICATE EXAMINATION, 2023

PHYSICS AND CHEMISTRY – HIGHER LEVEL

WEDNESDAY, 21 JUNE – MORNING, 9:30 to 12:30

Six questions to be answered.

Answer at least **two** questions from Section I, at least **two** questions from Section II and **any two other** questions.

All the questions carry equal marks.

However, in each section, one additional mark will be given to each of the first two questions for which the highest marks are obtained.

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.

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The 2023 examination papers were adjusted to compensate for disruptions to learning due to COVID-19. This examination paper does not necessarily reflect the same structure and format as the examination papers of past or subsequent years.

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*) State Newton's *third* law of motion.

(*b*) Dublin Port Tunnel is 4.5 km in length and has an 80 km per hour speed limit. Cameras at the entry and exit points are used to determine the average speed of a vehicle driving through the tunnel. See **Figure 1**. What is the minimum time, in minutes, to drive through the tunnel without exceeding 80 km per hour on average?

Figure 1

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

(*d*) When struck once with a hammer, a nail of mass 0.018 kg was given a horizontal initial velocity of 8.0 m s^{-1} and as a result its point penetrated horizontally 0.02 m into a block of wood before coming to rest.
Calculate the average force exerted by the wood on the nail.

(*e*) How does Brownian motion provide evidence for the kinetic theory?

(*f*) Explain how sample **X** of a liquid and sample **Y** of the *same* liquid could have the same temperature but contain different quantities of heat.

(*g*) A small gas cylinder of volume 7×10^{-5} m^3 contained 0.75 moles of carbon dioxide at a temperature of 293 K. What was the pressure, in Pa, of the gas inside the cylinder?

(*h*) What type of mirror forms an image at infinity of an object placed at its focus?

(*i*) Arrange the following forms of electromagnetic radiation in order of *increasing* wavelength:
gamma waves **infrared radiation** **x-rays** **violet light**

(*j*) What is meant by the diffraction of a wave?

(*k*) **Figure 2** represents a longitudinal wave moving to the right. **A** = 12 cm.
What is the wavelength of the wave?

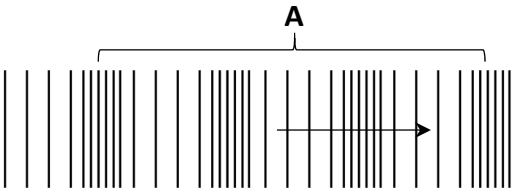

Figure 2

(*l*) Write an equation to define capacitance.

(*m*) What is a magnetic field?

(*n*) What is the total resistance of four 9 Ω resistors connected in parallel?

(*o*) Identify the type of device that changes a 230 V a.c. supply to a 5 V a.c. supply.

(*p*) Why are high voltages used to transmit electrical energy over long distances?

(*q*) What change takes place in an unstable nucleus when it emits a beta particle?

(*r*) **Figure 3** represents the last two stages of a radioactive decay chain. Identify the last isotope of the chain which is formed when a bismuth–211 nucleus emits an alpha particle, and then its daughter nucleus (**D**) emits a beta particle.

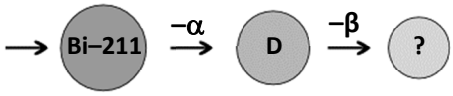

Figure 3

(11 × 6)

2. (*a*) Define (*i*) force, (*ii*) work.

(*iii*) What is the relationship between work and kinetic energy?

(*iv*) What quantity is defined as the rate of doing work?

Figure 4 shows how an architect incorporated an access ramp into a building design. A child of mass 21.0 kg used the ramp to enter the building, the floor of which is 2.5 m vertically above the ground.

Figure 4

(*v*) State the law of conservation of energy.

(*vi*) What was the potential energy gained by the child who entered the building?

(*vii*) For people entering and leaving the building, what is an advantage of a long, gently inclined ramp over a steeply sloped one? (33)

(*b*) The table below gives the work done when different forces were applied to a 32.0 kg mass to produce the same displacement, *s*, in each case.

Force (N)	0	15	30	45	55	70	80
Work (J)	0	460	900	1,360	1,640	2,060	2,380

(*i*) Plot a graph, on graph paper, to show the variation of work with force (*x*-axis).

(*ii*) What quantity can be determined from the slope of the graph?

(*iii*) Find the value of this quantity from your graph.

(*iv*) From your graph, or otherwise, find the work done if a force of 65 N had been applied.

(*v*) What was the final speed of the 32.0 kg mass, initially at rest, after the 65 N force was applied over displacement *s*, assuming any other forces can be ignored? (33)

3. (*a*) (*i*) State Charles' law.

A basketball filled with air, like that shown in **Figure 5**, had a volume of 7,100 cm^3 at 293 K.

(*ii*) By how much, to the nearest cm^3, did the ball shrink, when left outside on a cold night at 273 K?

Figure 5

The data in the table below shows the pressures (P) of a fixed mass of gas recorded at a number of different temperature (T) values. The volume is constant.

T (K)	100	150	200	273	325	350	400
P (kPa)	29	44	61	83	98	106	120

(*iii*) Plot a graph to show the variation of P with T.

(*iv*) What relationship between pressure and temperature is established by your graph? Justify your answer. (36)

(*b*) (*i*) What is meant by the triple point temperature of water?

(*ii*) The triple point of water is one of two fixed points used to define temperature on the Kelvin scale. What is the other fixed point?

(*iii*) The constant volume gas thermometer uses pressure as its thermometric property. Explain the underlined term.

(*iv*) Why is a constant volume gas thermometer used as a standard thermometer?

Temperature T on the Kelvin scale is defined by the expression

$$T = 273.16\left(\frac{P_T}{P_{tp}}\right)$$

where P_T and P_{tp} are pressure readings from a constant volume gas thermometer at temperature T and at the triple point temperature of water, respectively.

(*v*) Calculate the pressure at the triple point temperature in a constant volume gas thermometer that gave a pressure reading of 9.40×10^4 Pa at 313.15 K.

(*vi*) Write an expression for the relationship between temperature on the Kelvin scale T and temperature on the Celsius scale θ. (30)

4. (*a*) (*i*) What is refraction of light?

(*ii*) State Snell's law of refraction.

(*iii*) Describe, with the aid of a labelled diagram, an experiment to measure the refractive index of a rectangular block of glass.

State whether a change occurs in (*iv*) its speed, (*v*) its frequency, (*vi*) its wavelength, when a light wave undergoes refraction. (30)

(*b*) Images are formed by lenses as a result of the refraction of incident rays.

(*i*) Distinguish between a real and a virtual image.

(*ii*) Draw a diagram to show the formation of a virtual, upright, magnified image by a convex (converging) lens.

(*iii*) An object is placed 4 cm from a convex (converging) lens. A virtual image is formed 5 cm from the lens. Calculate the focal length of the lens. (18)

(*c*) Irish scientist John Tyndall demonstrated around 1870 how light could be 'piped' along a stream of water. A modern version of this demonstration using a laser beam as the light source is shown in **Figure 6**.

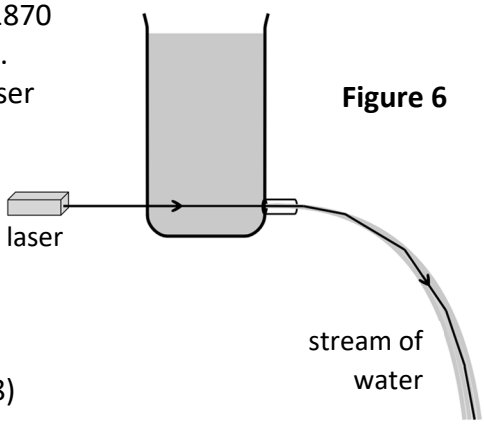

Figure 6

(*i*) Identify the phenomenon that confines the laser light to the stream of water.

(*ii*) What is meant by the critical angle of a material?

(*iii*) Calculate the critical angle for water if the refractive index for water is 1.33. (18)

5. An electric current is the flow of charge through a conductor.

(*a*) (*i*) Identify the charge carriers when the conductor is a copper wire.

(*ii*) Distinguish between a *direct* current and an *alternating* current.

(*iii*) Describe how you would demonstrate the magnetic effect of a direct current.

(*iv*) Identify another possible effect of a current flowing in a conductor. (24)

(*b*) (*i*) State Ohm's law.

Calculate the current flowing

(*ii*) in a 4.0 Ω resistor connected to a 9.0 V supply,

(*iii*) in the element of a 2.5 kW kettle connected to a 230 V supply,

(*iv*) in the 29.4 Ω element of a 1.8 kW toaster when it is switched on. (24)

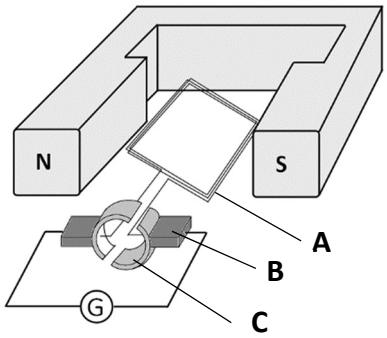

Figure 7

(*c*) A dynamo, like that shown in **Figure 7**, produces a direct current by electromagnetic induction.

(*i*) Identify the parts labelled **A**, **B** and **C**.

(*ii*) What is the main energy conversion taking place as the current is generated?

(*iii*) State one way of increasing the size of the current generated. (18)

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

(*a*) (*i*) Distinguish between the mass and the weight of an object.

(*ii*) State Newton's law of universal gravitation.

(*iii*) Derive an expression for the relationship between g, the acceleration due to gravity and G, the gravitational constant.

(*iv*) Pluto is a dwarf planet in our solar system. A small mass, released from rest close to the surface of Pluto, radius 1.19×10^6 m, would experience an acceleration of 0.620 m s^{-2} towards the centre of Pluto. Calculate the mass of Pluto.

(*v*) Pluto's largest moon is Charon. When an object is 1.45×10^7 m from the centre of Pluto and 5.10×10^6 m from the centre of Charon, as shown in **Figure 8**, the gravitational forces due to Pluto and Charon cancel. Calculate the mass of Charon. (33)

Figure 8

(*b*) (*i*) What is a photon?

What is meant by (*ii*) the frequency, (*iii*) the wavelength, of a wave?

(*iv*) Calculate the wavelength of the wave associated with photons of energy 7.5×10^{-19} J.

Some photons cause electrons to be released from the surface of a metal.

(*v*) Identify this phenomenon.

(*vi*) Explain why only some photons cause this phenomenon. (33)

(*c*) (*i*) In terms of subatomic particles, how does a positive charge arise on an object?

Draw separate diagrams to show

(*ii*) the distribution of positive charge on a metal sphere mounted on an insulated stand,

(*iii*) the electrical field around this sphere.

(*iv*) Give one use for a gold-leaf electroscope.

(*v*) State Coulomb's law of force between two charges.

(*vi*) F is the force between two insulated metal spheres, with charges $+Q$ and $-Q$ respectively, and their centres separated by a distance d. In terms of F, what was the force between the spheres when the distance between their centres was increased to $3d$? (33)

(*d*) Categorise each of the following nuclear reactions as either a fission or a fusion reaction:

(*i*) $^{235}_{92}\mathbf{U} + {}^{1}_{0}\mathbf{n} \rightarrow {}^{92}_{36}\mathbf{Kr} + {}^{141}_{56}\mathbf{Ba} + 3{}^{1}_{0}\mathbf{n}$ **+ energy**,

(*ii*) $2{}^{3}_{2}\mathbf{He} \rightarrow {}^{4}_{2}\mathbf{He} + 2{}^{1}_{1}\mathbf{H}$ **+ energy**.

(*iii*) Explain why a nuclear chain reaction could arise in uranium–235 as a result of reaction (*i*).

(*iv*) Give one application of fission reactions.

(*v*) Use data from page 83 of the *Formulae and Tables* booklet to calculate the mass loss in unified atomic mass units (u) for each **He**–4 nucleus produced in (*ii*) above.

Then use data from page 47 of *Formulae and Tables* to calculate the energy in joules (J) released for each of these **He**–4 nuclei produced. (33)

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, are there in a $^{9}_{4}\mathbf{Be}^{2+}$ ion?

(*b*) **Figure 9** represents the 9 *outer* electrons in the 4*s* and 3*d* sub-levels of a neutral atom of a certain transition element in its ground state. What is the element?

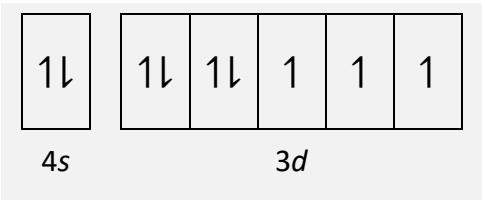

Figure 9

(*c*) Calculate a value for the relative atomic mass of a sample of neon composed of 91% neon–20 and 9% neon–22.

(*d*) Diamond and graphite are allotropes of carbon. What are allotropes?

(*e*) Write the chemical formulae for iron(II) sulfide and magnesium hydroxide.

(*f*) Identify the energy change associated with the following balanced equation:

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

(*g*) Find the chemical formula of the oxide of copper ($\mathbf{Cu_xO}$) that contains 11.2% by mass of oxygen.
[**O** = 16; **Cu** = 63.5]


Figure 10

(*h*) Identify (*i*) the conjugate acid, (*ii*) the conjugate base, of $\mathbf{HSO_3^-}$.

(*i*) Copy, complete and balance the equation:

$$\mathbf{HCl + CaCO_3} \rightarrow$$

(*j*) A nicotine skin patch like the one shown in **Figure 10** contains 14 mg of nicotine ($\mathbf{C_{10}H_{14}N_2}$). How many moles of nicotine are there in the patch?

(*k*) Starting with the metal most likely to donate electrons, arrange the elements **Ag**, **Cu**, **Fe**, **Na** and **Zn** in order of their decreasing tendency to donate electrons.

(*l*) Ice (solid $\mathbf{H_2O}$) and dry ice (solid $\mathbf{CO_2}$) are molecular crystals.
How are the molecules held together in a crystal of (*i*) ice, (*ii*) dry ice?

(*m*) What is an amphoteric oxide? Give an example.

(*n*) Define heat of solution.

(*o*) **Figure 11** shows the structure of a toluene molecule.
What is the molecular formula of toluene?

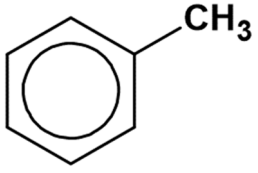

Figure 11

(*p*) Name the homologous series of hydrocarbons that has the general formula $\mathbf{C_nH_{2n+2}}$, where $n \geq 1$.

(*q*) What colour change would you expect to observe if a little of Fehling's reagent were heated gently in the presence of a few drops of an aldehyde?

(*r*) Draw the two possible structures of a molecule with formula $\mathbf{C_4H_{10}}$.

(11 × 6)

8. (*a*) Distinguish between
(*i*) an element and a compound,
(*ii*) an atom and a molecule,
(*iii*) ionic and covalent bonding. (18)

Figure 12

(*b*) (*i*) Define an atomic orbital.
Write the *s*, *p*, electron configuration for
(*ii*) a lithium atom,
(*iii*) a chlorine atom.

Lithium chloride (**LiCl**) is an ionic solid used to colour firework displays, like that shown in **Figure 12**.

(*iv*) Describe how you would carry out a flame test on a sample of **LiCl**.
(*v*) What colour does **LiCl** give to a flame? (24)

(*c*) (*i*) Define the electronegativity of an element.
(*ii*) On a single sheet of graph paper, referring to page 81 of the *Formulae and Tables* booklet, plot the electronegativity values (*y*-axis) *versus* atomic numbers for both the second period elements **Li** to **F** and the first four Group 17 elements **F** to **I**.
(*iii*) Explain the decrease in electronegativity values shown down Group 17.
(*iv*) Use electronegativity values to predict the type of bonding you would expect to occur in the compound $\mathbf{NF_3}$. (24)

9. Vinegar is a solution of ethanoic acid ($\mathbf{CH_3COOH}$) in water. To determine the concentration of ethanoic acid in a sample of vinegar, 25.0 cm^3 of the vinegar were diluted to exactly 250 cm^3 and then the diluted vinegar was titrated with a standard solution of potassium hydroxide. The equation for the titration reaction is:

$$\mathbf{CH_3COOH + KOH \rightarrow CH_3COOK + H_2O}$$

(*a*) (*i*) Explain the underlined term above.
(*ii*) Name the piece of apparatus shown in **Figure 13**.
(*iii*) Describe how the dilution could have been carried out. (18)

(*b*) Describe the correct procedure
(*i*) for rinsing a burette for use in this titration, and
(*ii*) then filling it with the diluted vinegar. (15)

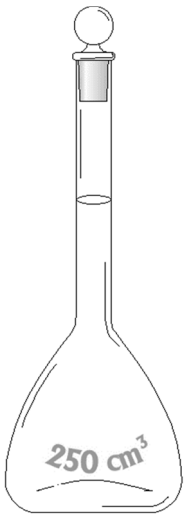

Figure 13

(*c*) (*i*) Name a suitable indicator for use in this titration.
(*ii*) What colour change would be observed at the end point of this titration?
(*iii*) Explain why it is advisable to use no more than 1 to 2 drops of indicator in a titration.
(*iv*) Calculate the molarity of the potassium hydroxide solution that contained 3.36 g of **KOH** per litre.

On average, 18.65 cm^3 of the diluted vinegar were required to neutralise 25.0 cm^3 of this **KOH** solution.
Calculate the concentration of $\mathbf{CH_3COOH}$
(*v*) in the diluted vinegar in moles per litre,
(*vi*) in the original vinegar in moles per litre,
(*vii*) in the original vinegar in grams per litre. (33)

10. (*a*) Define (*i*) oxidation, (*ii*) reduction, in terms of electron transfer.

(*iii*) Is each of the following reactions a redox reaction?

$$2Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$$

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Justify your answers.

Photochromic glass, containing Ag^+ and Cu^+ ions, darkens when exposed to the ultraviolet radiation in sunlight. See **Figure 14**.
The following reversible redox reaction occurs in the photochromic glass. The glass darkens as clusters of silver atoms are formed.

$$Ag^+ + Cu^+ \rightleftharpoons Ag + Cu^{2+}$$

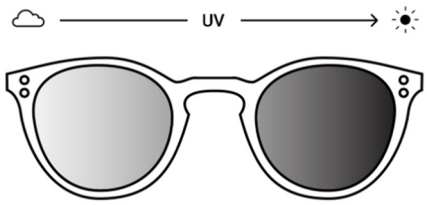

Figure 14

(*iv*) In bright sunlight which species is oxidised?

(*v*) When a person wearing photochromic glasses moves indoors on a sunny day, which species acts as the reducing agent causing the dark colour to fade? (30)

(*b*) Hydrogen produced by the electrolysis of water is described as 'green hydrogen' if renewable electricity is used, e.g. electricity generated from solar energy.
Figure 15 shows an apparatus used to electrolyse acidified water using inert electrodes and where the power supply is a solar panel.

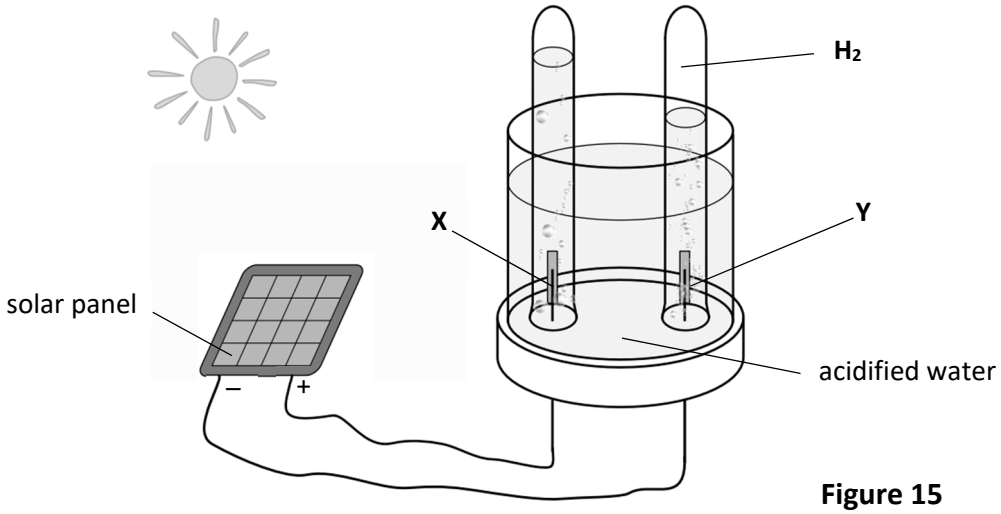

Figure 15

(*i*) What is meant by electrolysis?

(*ii*) Why were a few drops of acid added to the water before switching on the circuit?

(*iii*) State Faraday's first law of electrolysis.

The balanced equation for the cathode reaction is:

$$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)}$$

(*iv*) What charge passed in the circuit when a current of 0.75 A flowed in 10 minutes?

(*v*) What volume of hydrogen, measured at s.t.p., was collected in the 10 minutes?

(*vi*) What volume of oxygen, measured at s.t.p., was collected at the same time?

(*vii*) At which electrode, **X** or **Y**, did oxidation occur? (36)

11. Study the reaction scheme shown in **Figure 16** below and answer the questions that follow.

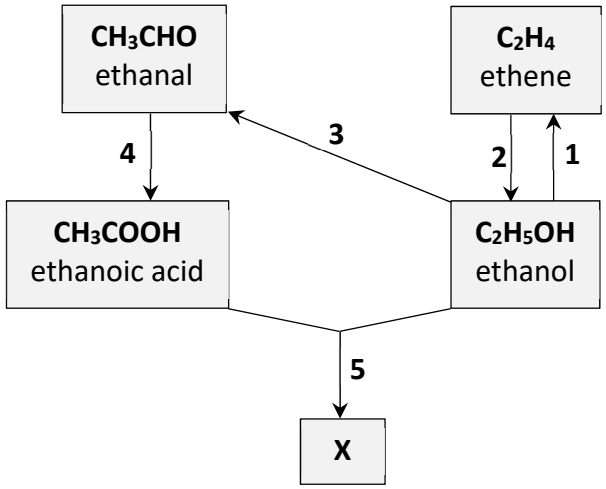

Figure 16

(*a*) (*i*) Ethene is a <u>hydrocarbon</u>.
Explain the underlined term.

(*ii*) Describe with the aid of a labelled diagram how ethene is prepared from ethanol by reaction **1** and collected over water in the laboratory.

(*iii*) Write a balanced equation for reaction **1**.

(*iv*) How could a test-tube of ethene be tested for unsaturation? (30)

(*b*) (*i*) Identify the substance that undergoes an addition reaction in the scheme *and* the inorganic substance added to it in this reaction.

(*ii*) Identify two oxidation reactions in the scheme *and* name a suitable oxidising reagent for these reactions.

(*iii*) Give the name of ester **X**.

(*iv*) Draw a diagram to show all of the atoms and all of the bonds in a molecule of **X**.

Explain why, in the scheme,

(*v*) the compound with the lowest boiling point is ethene,

(*vi*) the compound with the highest boiling point is ethanoic acid. (36)

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

(*a*) Antimony (**Sb**) is an element used in the electronics industry. Antimony is isolated from its ore, stibnite (Sb_2S_3), in the following reactions. Assume both reactions go to completion.

$$2Sb_2S_3\,(s) + 9O_2\,(g) \rightarrow 2Sb_2O_3\,(s) + 6SO_2\,(g)$$

$$Sb_2O_3\,(s) + 3CO\,(g) \rightarrow 2Sb\,(s) + 3CO_2\,(g)$$

In the first reaction 12.0 moles of sulfur dioxide were produced from a certain mass of stibnite. Then all the Sb_2O_3 formed reacted with **CO** to give antimony.

(*i*) How many sulfur (**S**) atoms were removed from the stibnite to form 12.0 moles of SO_2?

(*ii*) What mass of antimony was extracted from its ore in these reactions?

(*iii*) How many litres of **CO**, measured at s.t.p., were used up in the second reaction?

(*iv*) What is the valency of antimony in Sb_2O_3?

(*b*) (*i*) Draw a (dot and cross) diagram to show the arrangement of the valence electrons in a molecule of hydrogen sulfide (H_2S).

(*ii*) State the shape of a H_2S molecule.

(*iii*) Does a molecule of H_2S have an overall dipole moment?

XH_2 is a compound of hydrogen and another element **X**. Its molecules do not have an overall dipole moment. **X** is in the second period of the periodic table.

(*iv*) Identify **X**.

State (*v*) the shape of, (*vi*) the bond angle in, a molecule of gaseous XH_2.

(*c*) (*i*) State Hess's law.

Consider the following heats of reaction.

$$4B\,(s) + 3O_2\,(g) \rightarrow 2B_2O_3\,(s) \qquad \Delta H = -2{,}547.0\text{ kJ}$$

$$2H_2O\,(l) \rightarrow 2H_2\,(g) + O_2\,(g) \qquad \Delta H = 571.6\text{ kJ}$$

$$B_2O_3\,(s) + 3H_2O\,(l) \rightarrow B_2H_6\,(g) + 3O_2\,(g) \qquad \Delta H = 2167.3\text{ kJ}$$

(*ii*) Use Hess's law and the information given above to calculate the heat change for the following reaction.

$$2B\,(s) + 3H_2\,(g) \rightarrow B_2H_6\,(g)$$

Use the heats of reaction given above to calculate

(*iii*) the heat of combustion of boron (**B**),

(*iv*) the heat of formation of water.

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

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

(*iv*) Define pOH.

(*v*) What is the relationship between pH and pOH?

The pH of a **HCl** solution is 2.0 according to a pH meter as shown in **Figure 17**.

(*vi*) Calculate the concentration of the **HCl** solution in moles per litre.

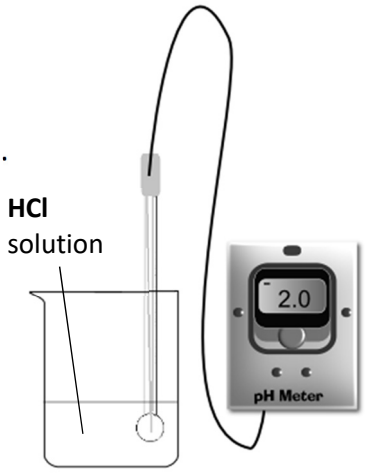

Figure 17

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Leaving Certificate – Higher Level

Physics and Chemistry

Wednesday, 21 June
Morning, 9:30 – 12:30