Question 15 (5 marks)

Analyse how the structure and chemistry of a commercial galvanic cell impacts the practicality of its uses. **5**

In your answer, refer to the dry cell OR lead-acid battery AND one other commercial galvanic cell of your choice.

Dry cells are comprised of a Zn anode that encloses a graphite cathode surrounded by powdered C and MnO_2 in an acidic NH_4Cl electrolyte. The relevant reactions are:

$$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2\,e^- \quad \text{Oxidation}$$

$$2\,MnO_{2(s)} + 2\,NH_4^+{}_{(aq)} + 2\,e^- \rightarrow Mn_2O_{3(s)} + H_2O_{(l)} + 2\,NH_{3(g)} \quad \text{Reduction}$$

$$Zn_{(s)} + 2\,MnO_{2(s)} + 2\,NH_4^+{}_{(aq)} \rightarrow Zn^{2+}_{(aq)} + Mn_2O_{3(s)} + H_2O_{(l)} + 2\,NH_{3(g)}$$

The dry cell has a relatively short working life because the Zn anode is oxidised to Zn^{2+} over time, and the acidic electrolyte further attacks the Zn casing. Moreover, the dry cell is non-rechargeable and thus it must be replaced rather frequently. The dry cell is also unsuitable for high-current applications. If current is drawn too rapidly, NH_3 gas accumulates as it cannot be adequately complexed to Zn^{2+}, leading to a drop in cell voltage. Such technical issues tend to limit the uses of dry cells to low-current household devices such as remote controls and torches.

Silver button cells consist of a Zn anode and powdered Ag_2O cathode in a KOH electrolyte paste. The relevant reactions are:

$$Zn_{(s)} + 2\,OH^-_{(aq)} \rightarrow ZnO_{(s)} + H_2O_{(l)} + 2\,e^- \quad \text{Oxidation}$$

$$Ag_2O_{(s)} + H_2O_{(l)} + 2\,e^- \rightarrow 2\,Ag_{(s)} + 2\,OH^-_{(aq)} \quad \text{Reduction}$$

$$Zn_{(s)} + Ag_2O_{(s)} \rightarrow ZnO_{(s)} + 2\,Ag_{(s)}$$

Unlike dry cells, silver button cells are able to deliver a fairly constant voltage and have a longer working life. All the reactants and products are solids with constant concentrations and the concentration of the KOH electrolyte also remains constant. This provides a stable voltage throughout the cell's lifetime, which is ideal for devices that require a reliable energy supply such as watches and pacemakers. Button cells are also small and compact due to the solid nature of their components, allowing them to be used in these miniature devices.

2 marks – Describes the chemistry of each cell by identifying anode, cathode and electrolyte, and providing relevant chemical equations

2 marks – Analyses how the structure/chemistry of each cell impacts their practicality (students must demonstrate a clear link between the structure/chemistry and practicality)

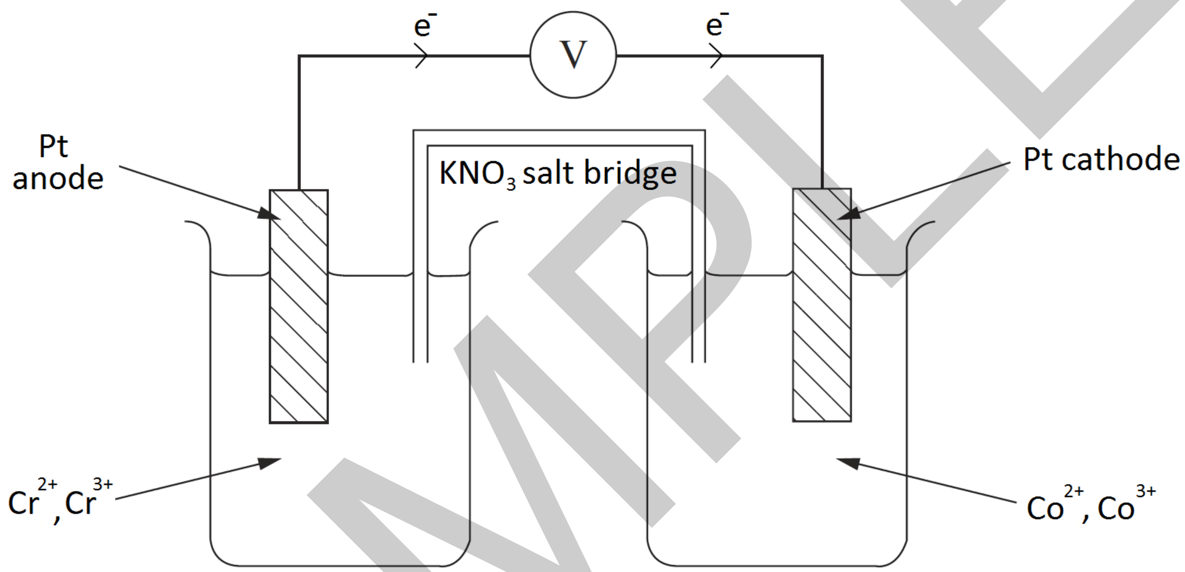
1 mark – Identifies specific uses for both cells relevant to the analysis

Question 16 (7 marks)
Two separate galvanic cells were provided to a student in a laboratory. The overall cell reactions and standard cell potentials for these galvanic cells are shown in the table below:

Cell	Overall cell reaction	$E^{\ominus}_{cell}$ (V)
1	$2\,Cr^{2+}_{(aq)} + Ni^{2+}_{(aq)} \rightarrow 2\,Cr^{3+}_{(aq)} + Ni_{(s)}$	0.18
2	$5\,Co^{3+}_{(aq)} + Mn^{2+}_{(aq)} + 4\,H_2O_{(l)} \rightarrow 5\,Co^{2+}_{(aq)} + MnO^{-}_{4\,(aq)} + 8\,H^{+}_{(aq)}$	0.41

The student then constructs a third galvanic cell using aqueous solutions of cobalt(II) nitrate, cobalt(III) nitrate, chromium(II) nitrate and chromium(III) nitrate, and any other relevant materials. A voltmeter is included so that the potential difference can be measured.

(a) Draw a diagram to illustrate the set-up required for this third galvanic cell. **2**



1 mark – Draws a galvanic cell with TWO correctly drawn half-cells (an inert electrode in Cr^{2+} and Cr^{3+} electrolyte and another inert electrode in Co^{2+} and Co^{3+} electrolyte)

1 mark – Draws a salt bridge and includes a voltmeter in the galvanic cell

(b) Using relevant calculations, deduce the direction of the electron flow of the galvanic cell in part (a), and clearly label it on the diagram above. **2**

Note: The $Co^{3+}|Co^{2+}$ and $Cr^{3+}|Cr^{2+}$ redox couples are NOT on the data sheet.

$Cr^{2+}_{(aq)} \rightarrow Cr^{3+}_{(aq)} + e^{-}$ $\quad E^{\ominus}_{ox} = 0.18\,V - (-0.24)\,V = 0.42\,V \implies E^{\ominus}_{red} = -0.42\,V$

$Co^{3+}_{(aq)} + e^{-} \rightarrow Co^{2+}_{(aq)}$ $\quad E^{\ominus}_{red} = 0.41\,V - (-1.51)\,V = 1.92\,V$

$\therefore$ The Pt electrode in the $Cr^{2+}|Cr^{3+}$ half-cell is the anode, while the Pt electrode in the $Co^{3+}|Co^{2+}$ half-cell is the cathode.

1 mark – Calculates the correct oxidation/reduction potential for both redox couples

1 mark – Clearly labels the direction of electron flow on the diagram

(c) Write a net ionic equation for the overall cell reaction occurring in the galvanic cell drawn in part (a), and calculate the expected standard cell potential. **2**

$Cr^{2+}_{(aq)} \rightarrow Cr^{3+}_{(aq)} + e^-$	$E^\ominus_{ox} = 0.42\,V$
$Co^{3+}_{(aq)} + e^- \rightarrow Co^{2+}_{(aq)}$	$E^\ominus_{red} = 1.92\,V$
$Cr^{2+}_{(aq)} + Co^{3+}_{(aq)} \rightarrow Cr^{3+}_{(aq)} + Co^{2+}_{(aq)}$	$E^\ominus_{cell} = 0.42\,V + 1.92\,V = 2.34\,V$

1 mark – Writes the correct net ionic equation for the overall cell reaction

1 mark – Calculates the correct standard cell potential

(d) Immediately after setting up the galvanic cell in part (a), the student noted that the value on the voltmeter was different to the standard cell potential calculated in part (c). **1**

Propose a reason for this observation.

The galvanic cell was not set up at 25°C with 1.00 mol L^{-1} electrolyte solutions. Without the use of these standard conditions, the voltage of the galvanic cell will vary from the standard cell potential.

1 mark – Suggests a reason for the deviation between the two values

Question 17 (5 marks)

The properties of two radioisotopes, X and Y, are summarised in the table below. **5**

Radioisotope	**Major type of emission**	**Half-life**
X	α	103 years
Y	β	46 hours

Evaluate the suitability of X, Y and ONE other medical radioisotope of your choice for their use in medicine.

Isotope X would not be suitable for medical purposes. The α radiation emitted by X is highly damaging to biological tissue as it induces DNA damage in cells and creates highly reactive free radicals due to its high ionising power. This is compounded by its very long half-life of 103 years, which would cause a patient to be exposed to excess radiation. The α radiation also has very low penetrating power and would not be detected outside the body.

Isotope Y may be suitable for *in vivo* therapy. The moderate ionising power of β radiation can be exploited to help kill rapidly-dividing cancer cells that preferentially take up the radioisotope. The relatively short half-life of 46 hours is also suitable to allow adequate time for therapeutic effect, but not too long as to cause excessive damage to healthy tissues.

Tc-99m is an extremely suitable radioisotope for nuclear diagnostic tests. It is reasonably reactive, so it can be tagged to many different molecules that localise to certain organs and tissues. Tc-99m emits highly penetrating γ rays, which can be detected outside the body to allow an assessment of the patient's organ function. The relatively short half-life of 6 hours is also suitable to limit the patient's exposure to damaging high-energy radiation.

2 marks – Evaluates X to be unsuitable for medicine in terms of emission and half-life

1 mark – Evaluates Y to be suitable for therapy in terms of emission and half-life

2 marks – Identifies an appropriate medical radioisotope and evaluates its use in medical diagnosis and/or therapy in terms of its emission type and half life

Question 18 (7 marks)

"Materials derived from biopolymers are rapidly becoming the most promising sustainable alternatives of the future." **7**

Assess the validity of this statement with reference to cellulose AND a recently developed biopolymer of your choice.

Biopolymers such as cellulose and Biopol/PHBV have great potential as renewable resources from which a variety of materials may be produced. Progress in applying these as sustainable alternatives, however, has largely been slow and limited by cost as well as various technical issues.

Cellulose, a condensation polymer of β-glucose, holds much promise as a renewable feedstock for the petrochemical industry. It is abundant in plant cell walls as the largest component of biomass, and has the basic carbon chain structures required to make a variety of materials. In fact, a pathway exists whereby cellulose can be hydrolysed to glucose, fermented to ethanol, then dehydrated to ethylene. Ethanol, in particular, is regarded as a promising alternative to petrol as a car fuel because it burns more cleanly and produces less CO_2 overall. Ethylene is also a crucial raw material for producing polymers such as polyethylene, PVC and polystyrene. The current process, however, of making ethanol and ethylene from cellulose is very expensive due to the high energy required to break strong hydrogen bonds between polymer chains. Much of this energy may be derived from fossil fuel combustion anyway. Even if ethanol were to be viably produced from cellulose, its capacity to totally replace petrol as a car fuel would be limited, as this requires costly engine modifications. As such, while cellulose and the materials derived from it have ample theoretical potential, many problems are still to be overcome with their use in practice.

PHBV or Biopol is a natural polyester produced by *Alcaligenes Eutrophus* bacteria as an energy storage material in response to cellular stress. Biopol exhibits many properties similar to crude oil derived polymers such as polypropylene, making it a promising and renewable material from which plastic products can be made. Biopol, however, has the advantage of being biodegradable i.e. it is readily decomposed when discarded into the environment, making it ideal for products such as disposable nappies and razors. It is also biocompatible, as it does not induce a vigorous immune reaction *in vivo*, making it useful for dissolvable sutures and vascular stents. While the notion of Biopol as a renewable plastic is exciting, it is prohibitively expensive to produce Biopol on an industrial scale at present because of the technical expertise involved. Research into making Biopol from genetically modified *E.coli* and transgenic plants has been promising, but has been substantially slowed by the relative lack of investment.

Although materials derived from cellulose and Biopol appear to be promising in theory, they are certainly not the "most promising" because translating such innovations into practice has proved much more difficult than expected. The statement is therefore largely invalid, since progress has been slow and the methods of production are not yet economically viable or sustainable.

2 marks – Describes cellulose and a recently developed biopolymer, explaining how the materials derived from them can be considered alternatives

4 marks –	Explains the advantages and/or disadvantages of materials derived from both biopolymers, with clear and relevant links to the statement
1 mark –	Assesses the validity of the statement with a clear judgement linked to the discussion