The total mark for this Data-based question is **24 marks**. You are advised to take at most 40 minutes to complete this question.

5 Climate change has forced manufacturers to look at alternative ways to store and generate electricity instead of using non-renewable fossil fuels. Batteries operating on redox principles have generated much traction and popularity.

Currently, lithium-ion batteries are used commercially in portable batteries and electric vehicles. They are the most ubiquitous batteries found in the market.

(a) Fig 5.1 is a diagram representing a simplified lithium-ion battery.

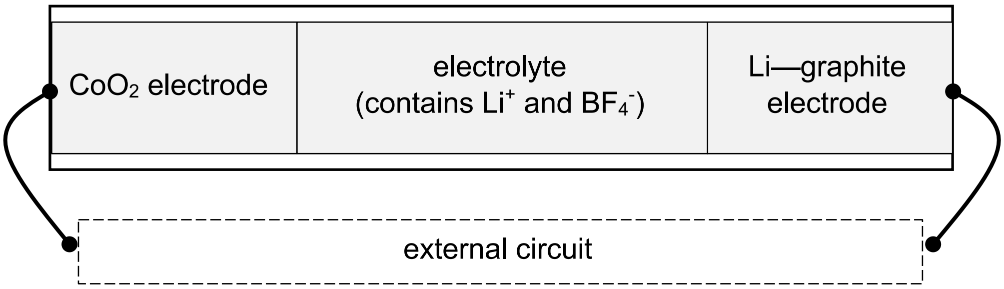

Fig 5.1

Lithium atoms are stored in graphite. During the discharge process, the Li—graphite electrode is the anode, while the CoO_2 electrode is the cathode. Li^+ ions migrate through the electrolyte to maintain charge balance.

The half equations, together with the standard reduction potentials, for the discharge process are shown in Table 5.1. The discharge process is spontaneous.

anode	$Li \rightarrow Li^+ + e^-$
cathode	$Li^+ + CoO_2 + e^- \rightarrow LiCoO_2$

Table 5.1

(i) On the diagram in Fig 5.1,

- indicate the direction of electron travel during the discharge process on the wires; and
- indicate the direction of Li^+ ion migration during the discharge process;

[1]

A battery's *charge capacity* is measured in mAh.

A portable charger said to have a charge capacity 10000 mAh is able to discharge a constant current of 1 mA (milli-ampere) for a total of 10000 hours. The discharge of the lithium-ion portable charger stops when half of the amount of CoO_2 is converted to $LiCoO_2$.

In a lithium-ion portable charger of charge capacity 10000 mAh, half of its mass is made up of the chemicals comprising the electrodes only.

(ii) Calculate the amount of electrons that will flow through the wires for a full discharge of a fully charged portable charger.

[2]

(iii) Find the **increase** in mass of the CoO_2 electrode after a full discharge of a fully charged portable charger.

[2]

(iv) The Li—graphite electrode contains 6 carbon atoms for every 1 lithium atom present when the portable charger is fully charged.

Given that the decrease in the mass of the Li—graphite electrode is 5% of the original weight of the Li—graphite electrode when the portable charger is fully charged, calculate the mass of the portable charger.

[4]

(v) The charge density of a battery is defined as the charge capacity per unit mass of the battery.

Calculate the charge density of the portable charger in mAh g^{-1}.

[1]

(b) When the lithium-ion battery was developed in the 1970s, metallic lithium was used as one of the electrodes. However, those batteries were dangerous and often caught fires after cycles of discharging and recharging due to the formation of 'dendrites'.

(i) In commercial lithium-ion batteries, lithium ions are trapped between layers of graphene in graphite. Fig 5.2 illustrates how lithium ions (represented as Li) are packed in the Li—graphite electrode.

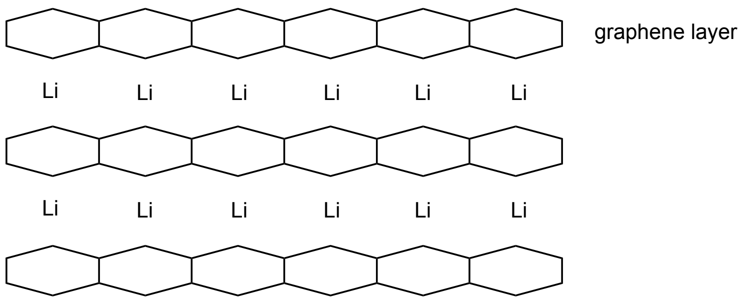

Fig 5.2

Compare the structure and bonding in the between the Li ions and graphene layers to that in metallic Li.

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(ii) Cycles of discharging and recharging caused 'dendrites' of lithium to grow uncontrollably from the lithium electrode. Fig 5.3 illustrates such a phenomenon.

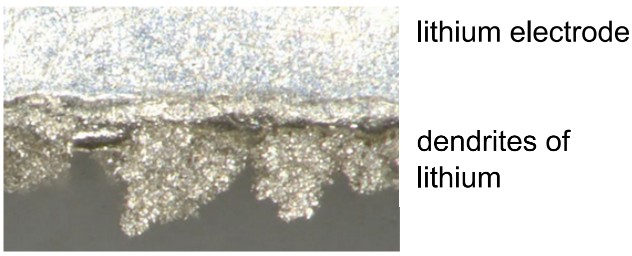

Fig 5.3

Eventually, these dendrites will grow and come into contact with the other electrode. Ignoring the danger this causes, suggest, with an explanation, what this does to the effectiveness of the battery.

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(c) Sodium-ion batteries work with the same principles as the lithium-ion batteries. However, the materials of the electrode are different.

Table 5.2 lists some of the characteristics of a sodium-ion battery, compared to its cousin, the lithium-ion battery.

	Na-ion	Li-ion
common materials of electrodes	Fe, Mn, Ti, Cu	Co, Ni
energy density / Wh kg^{-1}	75 to 200	120 to 260
charge capacity per unit mass / mAh g^{-1}	150 to 200	300 to 360
cost per kWh of energy stored / USD kWh^{-1}	4 to 16	24 to 67
materials of electrolytes	polar aprotic organic solvents	

Table 5.2

(i) State a common property amongst the metals used to make the materials of the electrodes and hence suggest why these metals are used to make the electrodes.

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....[2]

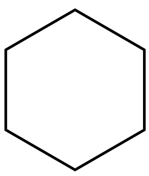
(ii) Suggest why the charge capacity of a Na-ion battery is typically lower than a Li-ion battery. Ignore any reference to materials used in the electrodes or electrolytes.

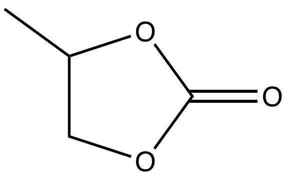
....

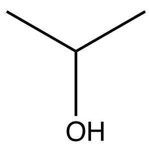
....[1]

(iii) A protic molecule is a molecule that has a hydrogen atom capable of being involved in hydrogen bonding. An aprotic solvent, however, lacks such hydrogen atoms.

Choose a suitable organic solvent from the organic molecules below that may be used in the electrolyte of both Na-ion and Li-ion batteries. (Circle one)







[1]

(iv) Suggest why the solvent must be polar and aprotic.

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(v) Suggest a hazard of using organic solvents as the electrolytes.

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(vi) Although the energy density and charge density of the Na-ion battery is generally lower than that of the Li-ion battery, the Na-ion battery is still preferred over the Li-ion battery in some energy storage systems.

By considering the materials used to make the batteries, suggest why Na-ion batteries are still preferred in some scenarios. Ignore any reference to cost.

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(vii) Which battery (Na-ion or Li-ion) is more suitable for storing energy for the following systems?

- electric vehicles: _____________
- excess energy from a solar farm in a power grid: ______________

[1]

(d) Explain two advantages of using rechargeable batteries over fossil fuels to provide energy for our daily needs.

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[Total: 24]