7 Read the following article and answer the questions that follow.

Batteries for Electric Vehicles (EV)

EV are vehicles that use electric motors for propulsion. The battery is a key component in such a vehicle. In the last few years, there have been great advancements in the development of batteries for use in EV that enable a greater energy capacity and allow charging in fast and simple ways.

Model X is a series of EV from a particular manufacturer. Fig. 7.1 shows the improvement in the battery capacities of various versions of model X over the years.

Year	Model name	Capacity / kWh
2011	X (2011)	16.0
2013	X (2013)	22.0
2015	X (2015)	27.5
2017	X (2017)	33.0
2020	X (2020)	42.0

Fig. 7.1

Lithium-ion batteries (Li-ion) are used in model X. The manufacturer has chosen the Li-ion over other types of batteries for some of its superior characteristics, as shown in Fig. 7.2.

Working Temperature / °C	−20 to 60
Specific Energy / Wh kg^{-1}	275
Energy Density / Wh cm^{-3}	0.200
Specific Power / W kg^{-1}	2500
Cell Voltage / V	3.6
Charge/Discharge Efficiency	80 to 90%
Self discharge rate	0.35% to 2.5% per month
Cycle Durability	400 to 3000

Fig. 7.2

Li-ion can be a safety hazard since they contain a flammable electrolyte and may become pressurised if they become damaged. A battery cell that is charged too quickly could also cause a short circuit, leading to explosions and fires.

(a) The battery capacity represents the maximum amount of energy that can be extracted from the battery under certain specified conditions.

(i) Calculate the battery capacity, in SI base units, of the model X (2020).

capacity = ……. SI base units: ……. [3]

(ii) The battery capacity of model X increases over the years.

Suggest an advantage of having a large battery capacity in an EV.

……..……..

..……..…….. [1]

(b) When fully charged, Li-ion can provide large amount of stored energy as compared to other types of batteries.

(i) State what is meant by the *specific energy* of a battery.

……..……..

..……..…… [1]

(ii) Calculate the mass of the batteries used in model X (2020).

mass = …… kg [2]

(iii) The batteries are one of the heaviest components in an EV.

Explain why it is important to position the batteries low down in the EV.

……..…….

……..…….

..……...…….. [2]

(c) The energy density is the amount of energy stored in a given battery per unit volume. This characteristic for the Li-ion used in model X has not changed since 2011.

(i) Fig. 7.3 shows how the volume of the batteries used in model X has changed over the years.

Year	Volume / 10^3 cm^3
2011	80
2013	110
2015	138
2017	
2020	210

Fig. 7.3

Complete Fig. 7.3 for the year 2017. [1]

(ii) Fig. 7.4 is a graph of the data of Fig. 7.3.

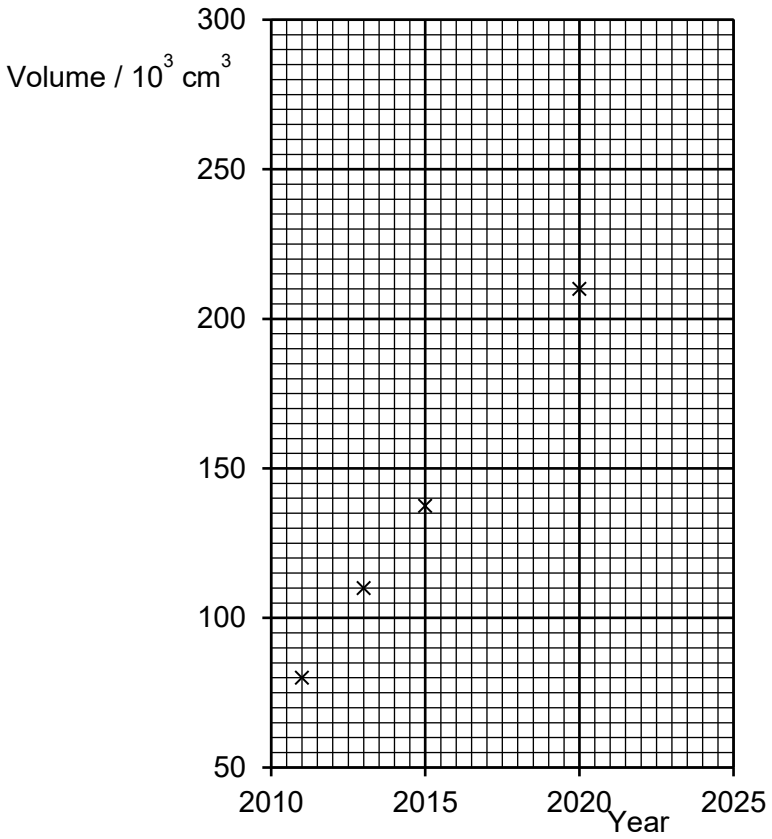

Fig. 7.4

Complete Fig. 7.4 using your data for the year 2017, and draw the line of best fit for all the points. [2]

(iii) The chassis of model X has a volume of 1.0×10^7 cm^3. It is proposed that to ensure sufficient space in the EV, the volume of the batteries should not occupy more than 2.6% of its total volume.

Estimate from Fig. 7.4 when this limit would be reached. Show your working clearly.

year = …… [2]

(d) The model X (2020) has batteries made by connecting several Li-ion cells to achieve a high voltage.

(i) Determine the number of Li-ion cells required to achieve the working voltage of 414 V. State how the cells should be arranged.

number of cells = ……

..……..…….. [2]

(ii) Suggest two reasons why it is important to monitor the temperature of the batteries.

……..……..

……..……..

……..……..

..……..…….. [2]

(e) A new model X that is to be released in 2022 uses 175 kg of batteries with the same specific power listed in Fig. 7.2. Specific power is the maximum power that a battery can supply per unit of its mass.

The electric motors used for propulsion in the new model X has an efficiency of 72%.

Calculate the maximum propulsion power that can be produced.

power = …… kW [2]

End of Paper