7 Read the passage below and answer the questions that follow.

It has been announced that, by 2040, cars using an internal combustion engine (ICE) will be phased out in Singapore. All new cars after 2040 will be electric vehicles (EVs). In Singapore, a car typically travels 290 km a week. The average range of a car using an ICE is 800 km. The average cost to refuel an ICE car is S$80.

At present, some drivers in Singapore have concerns about this phasing out of ICE cars. EVs are more expensive to buy, the number of public charging points is at present very limited, the time to charge is substantial, and there are also environmental issues such as the recycling of old batteries. In addition, the range of an EV from one charge is not as great as the range of an ICE car using one tank of fuel.

Many of these concerns may be resolved by supply and demand. The price of EVs will decrease as the technology becomes more mainstream. It is predicted that by 2025 the cost of owning an EV will be the same as that of owning an ICE car. Once there is a market for public charging points, more will be installed. At present, there are about 1600 public charging points in Singapore, and this should increase to 28 000 over the next ten years.

Table 7.1 shows data for a typical EV. This typical EV is similar to those that are currently available on the market.

Table 7.1

battery capacity	72 kW h
range	400 km
time to accelerate 0–100 $km\,h^{-1}$	7.6 s
total mass of EV	1685 kg
maximum output torque	395 N m

The typical EV uses a rechargeable battery that is located under the floor of the EV. The battery is made up of an arrangement of many individual cells, and it uses a technology that is very similar to that of batteries in laptop computers. The battery can be charged approximately 4000 times before requiring replacement. The home battery charger for the typical EV uses an a.c. supply to provide power of 7.2 kW with an equivalent direct current of 32 A. The battery takes 10 hours to fully charge – the manufacturer describes this as a ‘charging speed’ of 40 $km\,h^{-1}$. When fully charged, the battery has a specific energy of 141 $W\,h\,kg^{-1}$.

EVs can use regenerative braking systems to extend driving range. This is where the kinetic energy of the EV is used to charge the battery, rather than being converted into thermal energy by the brakes. This system is activated by the driver, so it does not automatically happen every time the EV brakes.

One recent advance in battery technology is the use of wireless charging. A simple wireless charger uses a 1.0 m^2 pad on the ground containing a coil of wire. This is attached directly to the a.c. electricity grid. A second coil is contained in a pad inside the EV, with the pad positioned as close to the ground as possible. The arrangement operates in a very similar way to the way in which a transformer works. In the future, it may be possible to have charging coils of wire built into the road network that continuously top up the batteries in EVs.

(a) (i) The cost of electrical energy is S$0.23 per kWh.

Calculate the ratio:

$$\frac{\text{cost to travel 1.0 km in the typical EV}}{\text{cost to travel 1.0 km in an ICE car}}.$$

ratio = ... [1]

(ii) State why EVs for use in Singapore typically need to be charged less than once per week.

....

.... [1]

(b) (i) Each individual cell in the battery of the typical EV has a maximum allowable charging current of 2.0A. Each cell has a maximum terminal voltage of 3.0V when being charged.

By considering the arrangement of cells in the battery, use the information and data from the passage to determine the minimum number of cells in the battery of the typical EV.

....

....

....

.... [3]

(ii) Suggest what the manufacturer means by a 'charging speed' of $40\,\mathrm{km\,h^{-1}}$.

....

.... [1]

(iii) Suggest what is meant by a specific energy of $141\,\text{W h kg}^{-1}$.

....

....

.... [1]

(iv) Determine the mass of the battery.

mass = ... kg [1]

(v) Use your answer to **(b)(iv)** to suggest a physics-based reason for the location of the battery.

....

....

.... [1]

(c) Battery chargers sometimes need to convert a.c. into d.c.

(i) Complete Fig. 7.1 using a single component to convert the a.c. input voltage into a d.c. output voltage.

Fig. 7.1

[1]

(ii) The a.c. input voltage varies with time and has a period T.

On Fig. 7.2, sketch the variation with time of the d.c. output voltage in **(c)(i)** for **two** cycles of the a.c. input.

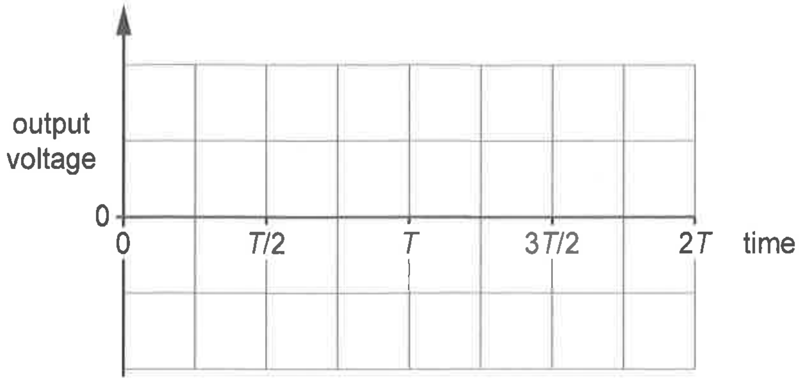

Fig. 7.2

[2]

(d) The typical EV is travelling at a speed of $25\,\mathrm{m\,s^{-1}}$ when the driver activates the regenerative braking system. The EV decelerates to rest and all its kinetic energy is used to charge the battery.

Determine the distance the EV can travel on this regenerated energy.

distance = ... km [3]

(e) **(i)** Explain why a wireless charger needs to use an a.c. voltage rather than a d.c. voltage.

....

.... [1]

(ii) Explain why the coil in the ground pad of a wireless charger and the coil in an EV need to be as close together as possible.

....

.... [1]

(f) Fig. 7.3 shows the coil of a simple electric motor between the poles of a magnet.

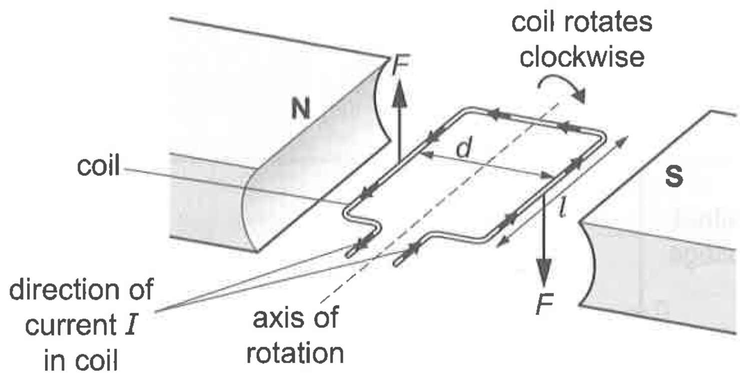

Fig. 7.3

The coil has length l and width d. The entire coil lies within the magnetic field. The magnetic flux density between the poles of the magnet is B. There is a current I in the coil.

Two forces, each of magnitude F, act in opposite directions on the two sides of the coil, as shown in Fig. 7.3. This produces a torque that causes the coil to rotate.

(i) The current I in the coil is 96 A. The area of the rectangular coil in the magnetic field of the magnet is $6.1 \times 10^{-3}\,\text{m}^2$ and the coil contains 1200 turns.

Calculate the magnetic flux density B needed to produce the maximum output torque of the typical EV.

B = ... T [3]

(ii) A simple motor uses one pair of magnetic poles, as shown in Fig. 7.4.

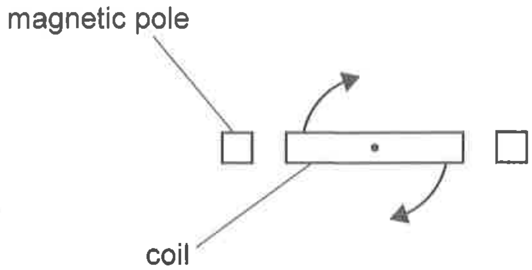

Fig. 7.4

A more practical motor uses four pairs of magnetic poles arranged around the coil, as shown in Fig. 7.5.

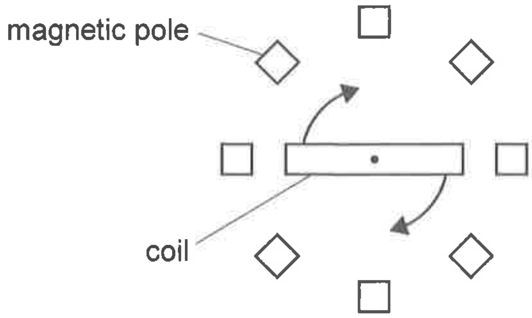

Fig. 7.5

Suggest an advantage of the arrangement shown in Fig. 7.5.

....

....

.... [1]

[Total: 21]

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