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

Physics of Microwave Oven

Microwaves are electromagnetic (e.m.) waves that have frequencies ranging from 300 MHz up to 300 GHz. Following international conventions, microwave ovens operate at frequencies at around 2.45 GHz.

Fig. 7.1. depicts a typical microwave oven. Microwaves are generated in magnetron which feeds via a waveguide into the cooking chamber. The cooking chamber has metallic walls which are able to perfectly reflect the microwaves fed into the cooking chamber, whilst the front door of the microwave oven is made of glass and is covered by metal grids. The holes in the metal grids are usually 100 times smaller than the wavelength of the microwaves, hence the walls and the grids act like a Faraday's cage, which is a safety feature.

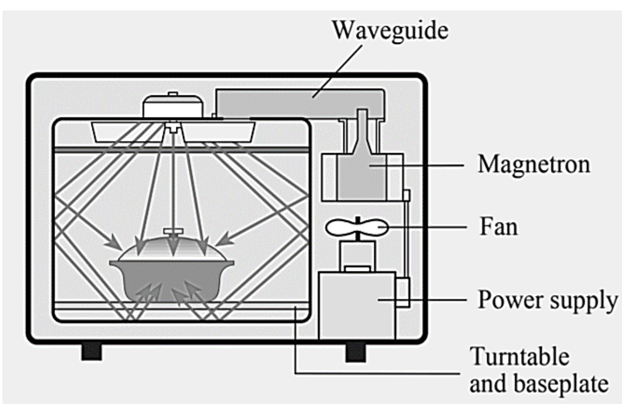

Fig. 7.1. Schematic diagram of a typical microwave oven

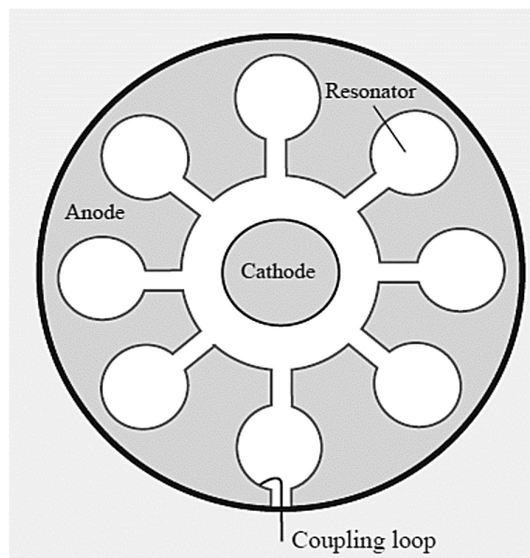

Fig. 7.2. Schematic diagram of a magnetron

Fig. 7.2 shows the schematic diagram of a magnetron. A cylindrical cathode is at the central axis, several millimetres from a hollow circular anode. Inside the anode there are a number of cavities known as resonators which allow for resonance at 2.45 GHz. A voltage of 5.00 kV is applied between the electrodes and a magnetic field is applied parallel to the axis such that the electric and magnetic fields are perpendicular to each other. In the magnetron, the combined effect of electric and magnetic fields causes the electrons emitted from the hot cathode to travel in curved paths.

So how does the interaction of the molecules in food with the microwaves produce a heating effect to cook food? The water molecules in food oscillate in the alternating electric field of the microwaves. As the individual molecules oscillate, the work done against the forces between neighbouring molecules increases their kinetic energy in a random manner, raising the temperature of the food. Fat, sugar and salt in food are able to heat up through a similar mechanism though they often play a smaller role as they are less abundant than water.

The absorption of microwaves by water molecules in the food, is often described as resonance, but this is not true: free water molecules resonate at 22 GHz and 183 GHz. Microwaves with a frequency of 22 GHz would be totally absorbed in the surface of the food without penetrating. If waves with a frequency as low as 100 MHz were used, they would pass straight through the food, and it would not heat up. The choice of 2.45 GHz is a compromise.

Upon entering foods, the intensity of microwaves is gradually reduced along its path according to the relationship:

$$I = I_0 e^{-\mu z}$$

where I_o is the intensity of the microwaves incident on the surface of the food, I is the microwave intensity in the food at a distance z below the surface and μ is a constant known as the attenuation coefficient.

Another method to characterise the penetration of microwaves in food is using a quantity known as *penetration depth* δ_p. It is a quantity that is dependent on the frequency of microwaves incident on the food and is defined as the distance at which the microwave intensity is reduced to 1/e (e = 2.718) from the intensity at the point of entry.

Passage extracted and adapted from "Physics of Microwave Oven" by Michael Volmer and OCR Jan 2004 Paper 2865.

(a) **(i)** Suggest what is the function of a 'Faraday's cage'.

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………………………………………………………………………………..…………... [1]

(ii) Estimate a suitable spacing for the holes in the metal grids used in the front door of a microwave oven.

spacing = ……………………………….m [2]

(b) Fig. 7.3 shows a simplified model of part of the magnetron. The electric field between the cathode and anode is illustrated.

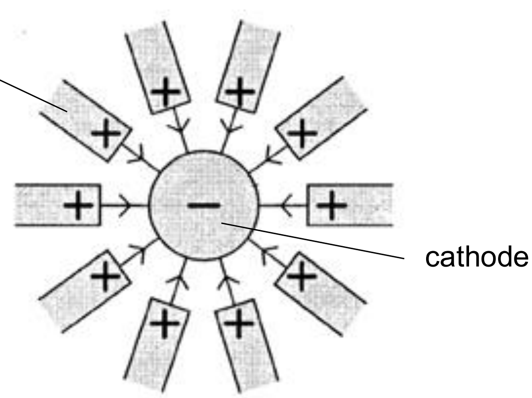

Fig. 7.3

(i) Show that the maximum kinetic energy that an electron can gain when moving to the anode is 8.0×10^{-16} J.

[1]

(ii) Hence, if the microwave power output of the magnetron is about 1000 W, determine the least number of electrons that must be emitted by the cathode each second.

least number of electrons per second = …………………………….s^{-1} [1]

(iii) Suggest one reason why the actual number of electrons emitted is likely to be larger than your answer to **(b)(ii)**.

…………………………………………………………………………………...................

……………………………………………………………………………………………….. [1]

(iv) Fig. 7.4 shows the trajectory of an electron of mass *m* and charge *q* moving at a speed *v* in the magnetic field of flux density *B* inside a magnetron.

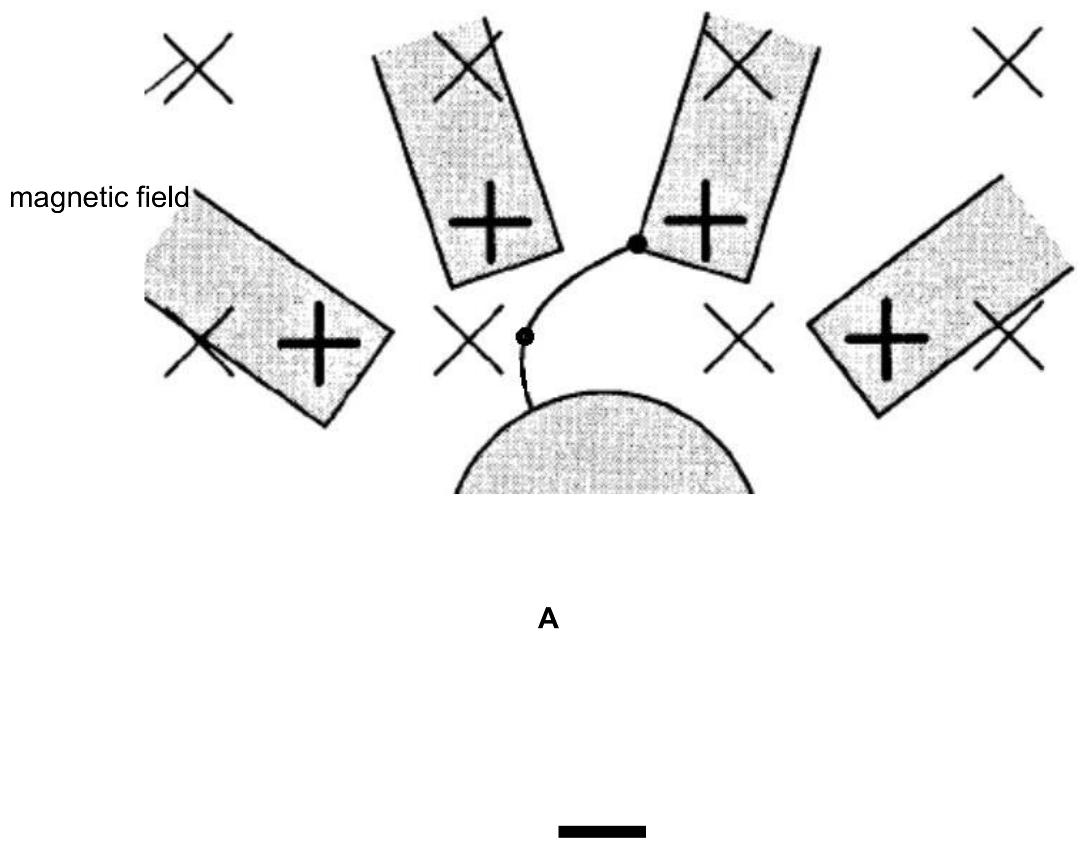

Fig. 7.4

1. On Fig. 7.4, draw and label the forces acting on the electron at A. [2]

2. State and explain how the introduction of the magnetic field will affect the maximum kinetic energy gained by an electron when moving to the anode calculated in **(b)(i).**

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………………………………………………………………………………….…………..... [2]

(c) An experiment is conducted to investigate the penetration of microwaves of frequency 2.45 GHz for a sample of potato mash.

Fig. 7.5 shows the readings obtained for the experiment.

depth into food z / mm	intensity of microwaves at depth z I / A.U.	ln (I / A.U.)
0	24	3.18
4	19	2.94
8	15	
12		2.49
16	10	2.30

Note that intensity I is measured in arbitrary units (A.U.)

Fig. 7.5

(i) Complete Fig. 7.5 for z = 8 mm and z = 12 mm. [2]

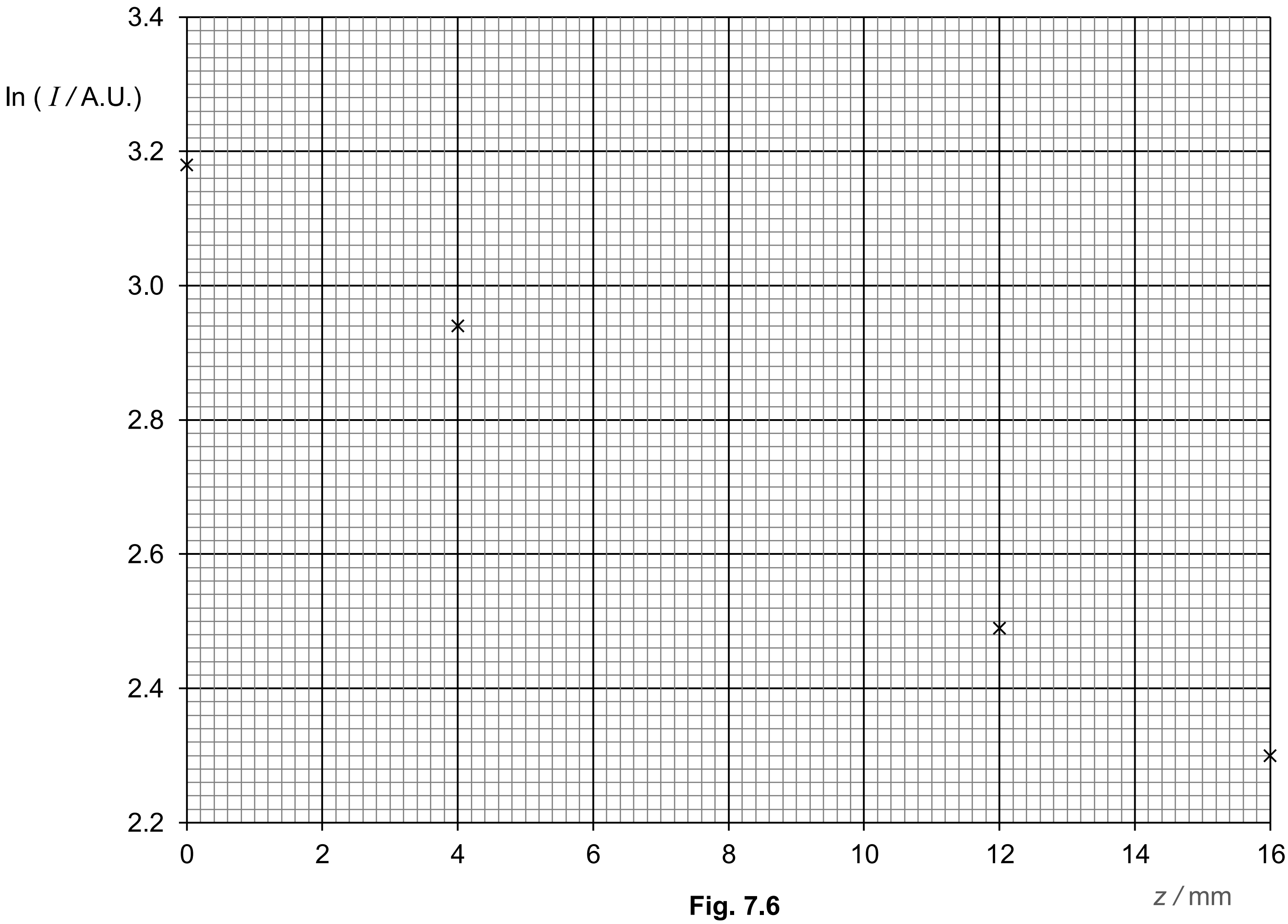

Fig. 7.6

(ii) A graph of ln (I / A.U.) with (z / mm) is shown in Fig. 7.6.

1. On Fig. 7.6, plot the point corresponding to z = 8 mm. [1]

2. Draw the best fit line for all the points. [1]

(iii) Determine the gradient of the line you have drawn.

gradient = ………………………………. [2]

(iv) Hence, determine the penetration depth δ_p for the potato mash.

δ_p = ………………………………mm [2]

(v) The experiment is then repeated with a potato mash of higher water content.

1. Suggest and explain how the penetration depth will differ from that found in **(c)(iv).**

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2. Sketch on Fig. 7.6, the new graph of ln(I / A.U.) with (z / mm) for this experiment. Label this graph **N**. [1]

[Total: 21]