Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

For Examiner's Use

General Certificate of Education
June 2008
Advanced Level Examination

PHYSICS (SPECIFICATION B) **PHB5**
Unit 5 Fields and their Applications

Tuesday 17 June 2008 1.30 pm to 3.30 pm

For this paper you must have:
- a calculator
- a ruler
- a loose insert containing formulae sheets and a comprehension passage to be used for Questions 6, 7, 8, 9, 10, and 11.

Time allowed: 2 hours

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Answers written in margins or on blank pages will not be marked.
- Do all rough work in this book. Cross through any work you do not want to be marked.
- The passage for answering Questions 6, 7, 8, 9, 10 and 11 is provided on the loose insert. Read the passage before answering the questions.

Information
- The maximum mark for this paper is 100. Four of these marks will be awarded for the Quality of Written Communication.
- The marks for questions are shown in brackets.
- You are expected to use a calculator where appropriate.
- You are reminded of the need for good English and clear presentation in your answers. Questions 4(c) and 8 should be answered in continuous prose. Quality of Written Communication will be assessed in these answers.
- The *Formulae Sheet* is provided on the loose insert to this paper.

For Examiner's Use			
Question	Mark	Question	Mark
1		9	
2		10	
3		11	
4			
5			
6			
7			
8			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

Answer **all** questions.

1 In 2006 Pluto was reclassified as a dwarf planet rather than a planet. Pluto, and other such planets, take more than 200 years to complete an orbit around the Sun.

The following is some data for Pluto

distance from the Sun	=	5.9×10^{12} m
period of the orbit	=	248 years
radius of Pluto	=	1200 km
mass of Pluto	=	1.3×10^{22} kg

Other data

universal gravitational constant	=	6.7×10^{-11} N m^2 kg^{-2}
mass of the Sun	=	2.0×10^{30} kg
1 year	=	3.2×10^{7} s

1 (a) Show that the speed of Pluto in orbit is about 4.7 km s^{-1}. Assume that the orbit is circular.

(3 marks)

1 (b) The escape velocity is the velocity of an object at the surface of a planet that would allow it to be removed completely from the planet's gravitational field.
Calculate the escape velocity for an object on the surface of Pluto.

(3 marks)

1 (c) Pluto's atmosphere is mostly methane and nitrogen. The surface temperature is –220 °C and the atmospheric pressure is 0.30 Pa.

1 (c) (i) Calculate the number of moles of gas per m^3 in the atmosphere of Pluto.

universal molar gas constant = 8.3 $J\,mol^{-1}\,K^{-1}$

1 (c) (ii) Suggest why this value is so low.

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(4 marks)

10

Turn over for the next question

2 Radiocarbon dating is an effective tool in dating ancient wooden objects. The method uses radioactive carbon-14 ($^{14}_{6}C$) which decays to nitrogen (N) by the emission of a β^- particle. It has been estimated that the Earth and its atmosphere contain about 2.5×10^{30} atoms of radioactive carbon-14 which is assumed to remain fairly constant.

half-life of carbon-14 = 5700 years
Avogadro constant = $6.0 \times 10^{23}\,mol^{-1}$
1 year = $3.2 \times 10^{7}\,s$

2 (a) (i) Calculate the total activity of all the carbon-14 in the Earth and its atmosphere.

2 (a) (ii) Calculate the mass of carbon-14 that is formed in the upper atmosphere each second to replace the carbon-14 that decays.

(5 marks)

2 (b) Write down the complete nuclear equation for the decay of carbon-14.

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(3 marks)

2 (c) A sample of wood from a tree recently chopped down has an activity of 0.75 Bq. The activity of a sample of wood of equal mass from an old wooden boat has an activity of 0.52 Bq.

2 (c) (i) Calculate the approximate age of the boat. Give your answer in years.

2 (c) (ii) The carbon-14 content of the atmosphere may be higher now than when the boat was made. State and explain the effect this would have on the estimated age of the boat.

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(5 marks)

13

Turn over for the next question

3 (a) State **one** similarity and **one** difference between an electric field and a gravitational field.

Similarity: ....

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Difference: ....

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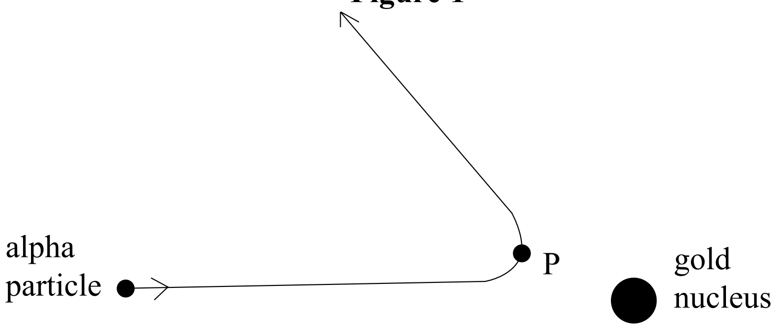
(2 marks)

3 (b) Rutherford used alpha particle scattering to determine the relative charge of different nuclei. **Figure 1** shows the path of an alpha particle (charge 2*e*) when it is near the gold nucleus (charge 79*e*)

Figure 1



At point **P** the separation of the centres of the alpha particle and the gold nucleus is 6.5×10^{-14} m.

magnitude of the electron charge $e = 1.6 \times 10^{-19}$ C
mass of an alpha particle = 6.8×10^{-27} kg
permittivity of free space = 8.9×10^{-12} F m^{-1}

3 (b) (i) Show that when the alpha particle is at point **P** its electrical potential energy is about 5.6×10^{-13} J.

3 (b) (ii) When the alpha particle was a long way from the gold nucleus, its kinetic energy was 7.2×10^{-13} J. Calculate the speed of the alpha particle as it moves through point **P**.

3 (b) (iii) Show on **Figure 1**, the path that the same alpha particle would follow if the gold nucleus had a higher proton number. *(7 marks)*

3 (c) State the effect of the collision on the gold nucleus and why this effect could be ignored in part (b)(ii).

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(3 marks)

12

Turn over for the next question

4 The table shows the masses of some particles and nuclei.

particle	**mass/10^{-27} kg**
${}^{1}_{1}p$	1.674
${}^{1}_{0}n$	1.675
${}^{235}_{92}U$	390.406
${}^{90}_{36}Kr$	149.357
${}^{144}_{56}Ba$	239.056

1 MeV = 1.6×10^{-13} J
speed of electromagnetic radiation = 3.0×10^{8} m s^{-1}
Avogadro constant = 6.0×10^{23} mol^{-1}

4 (a) The following reaction occurs in a nuclear reactor.

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{90}_{36}Kr + {}^{144}_{56}Ba + 2{}^{1}_{0}n $$

Calculate the mass change when 0.50 kg of uranium-235 undergoes fission by this reaction.

(3 marks)

4 (b) (i) Calculate the binding energy of a uranium-235 nucleus. Give your answer in J.

4 (b) (ii) Calculate the binding energy per nucleon. Give your answer in MeV.

(6 marks)

4 (c) Describe

- how energy is extracted from a hot nuclear reactor core to produce electricity
- how the power output of the reactor is controlled.

Two of the 8 marks are available are for the quality of your written communication.

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(8 marks)

17

Turn over ▸

5 **Figure 2** shows the side view of the principal components of a magneto-hydrodynamic propulsion system for a boat. **Figure 3** shows the cross-section through the system looking towards the water intake end. The system is fitted to the bottom of the boat as shown in **Figure 4**.

Figure 2

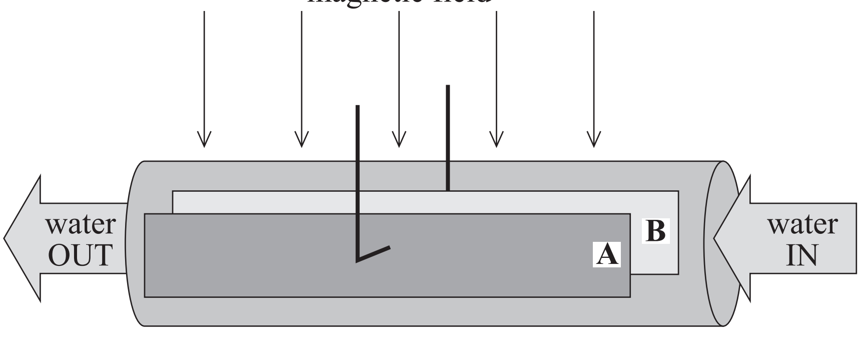


Figure 3

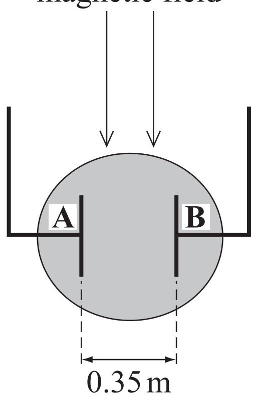
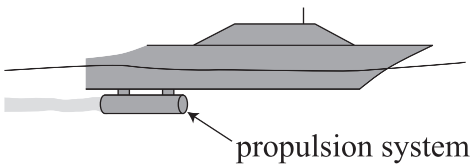


Figure 4



Diagrams not to scale

A potential difference of 50 V sets up a uniform electric field between the electrodes **A** and **B**. The electrodes are 0.35 m apart and each electrode has a surface area of 1.2 m^2. A vertical uniform magnetic field of flux density 3.0 T is produced by coils in the boat.

5 (a) Explain why the boat moves when the potential difference between **A** and **B** produces an electric current in the water.

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(4 marks)

5 (b) (i) Calculate the electric field strength in the region between the electrodes.

5 (b) (ii) The resistivity of sea water is 0.20 Ω m. Show that the current in the sea water is about 860 A.

(6 marks)

5 (c) The boat has **four** such systems to produce motion giving a top speed of 7.5 m s^{-1}.

5 (c) (i) Calculate the maximum thrust produced.

5 (c) (ii) Calculate the total power developed by the propulsion system when moving at top speed.

Question 5 continues on the next page

5 (c) (iii) Suggest **two** reasons why this propulsion system is not very efficient.

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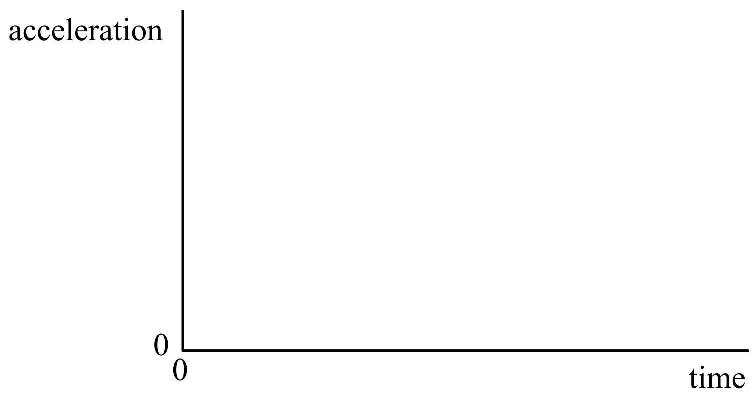
(7 marks)

5 (d) The thrust calculated in part (c)(i) is the maximum thrust and this is constant for all speeds. Calculate the initial acceleration of the boat of mass 1500 kg and sketch on the axes below a graph showing how the acceleration of the boat would vary with time when the boat starts from rest.



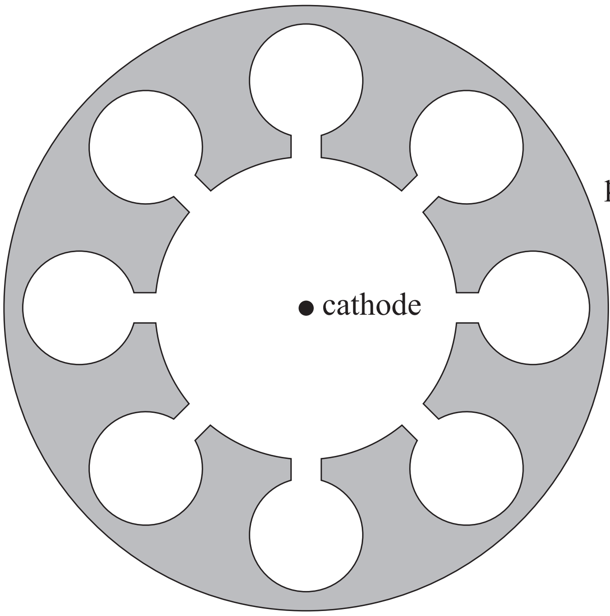
(2 marks)

19

The passage on the insert is for answering Questions 6 to 11.
Read the passage before answering Questions 6 to 11.

6 **Figure 5** shows part of a magnetron.

Figure 5



6 (a) Define the direction of an electric field.

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(1 mark)

6 (b) Draw on **Figure 5**, the *radial electric field*. Show the direction of the electric field.

(2 marks)

3

Turn over for the next question

7 (a) (i) Show that when the electrons reach the anode their velocity is about $4 \times 10^7\,\mathrm{m\,s^{-1}}$. Assume that the electrons leave the cathode with no kinetic energy.

7 (a) (ii) Calculate the magnetic flux density of the field that makes the electrons move in a circular path of radius 30 mm in the magnetron.

(6 marks)

7 (b) A designer suggests increasing the inside radius of the anode but keeping the magnetic field strength at the same magnitude. State and explain how the accelerating voltage would have to change if the new arrangement is to work.

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(3 marks)

9

8 Explain what is meant by 'transformer action' (line 17).

Two of the 6 marks are available for the quality of your written communication.

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(6 marks)

6

9 Calculate the number of photons emitted each second by the magnetron in the microwave oven (lines 19 - 21).

(2 marks)

2

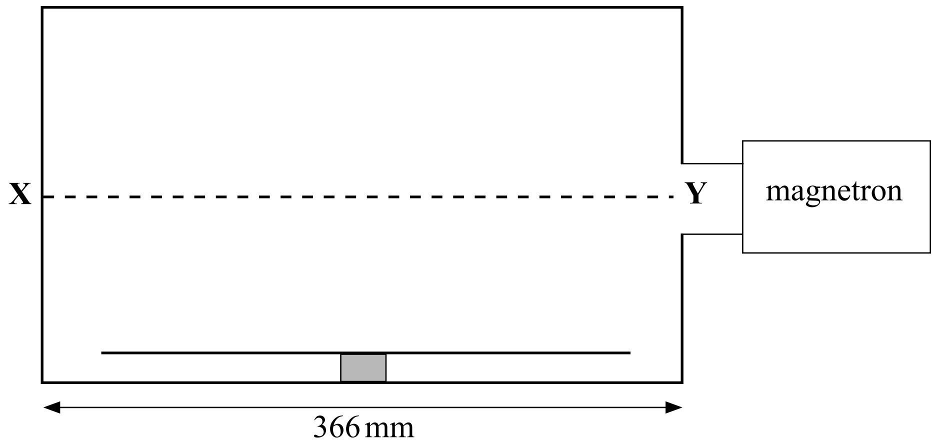
Turn over for the next question

10 The standing wave (line 25) could be set up when waves are reflected from the wall opposite the magnetron.

10 (a) (i) Calculate the wavelength of the microwaves in the oven.

10 (a) (ii) Draw on **Figure 6**, a standing wave that could be set up along **XY** for a microwave oven with a width of 366 mm. Assume that there is a node at **Y**.

Figure 6



(3 marks)

10 (b) Mark on the line **XY** in **Figure 6**, a point labelled **H** where the food would cook quickest. Explain your choice.

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(2 marks)

5

11 (a) Microwaves are dangerous. State **two** design features that prevent microwaves escaping from the oven.

First feature ....

Second feature ....

(2 marks)

11 (b) Suggest how energy is transferred to cook the inside of large items of food and why there is less need for 'waiting time' when heating liquids.

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(2 marks)

4

END OF QUESTIONS

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PHYSICS (SPECIFICATION B) **PHB5**
Unit 5 Fields and their Applications

Formulae Sheet

Foundation Physics Mechanics Formulae

moment of force $= Fd$

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$s = \frac{1}{2}(u + v)t$

for a spring, $F = k\Delta l$

energy stored in a spring $= \frac{1}{2}F\Delta l = \frac{1}{2}k(\Delta l)^2$

$T = \dfrac{1}{f}$

Foundation Physics Electricity Formulae

$I = nAvq$

terminal p.d. $= E - Ir$

in series circuit, $R = R_1 + R_2 + R_3 + \ldots..$

in parallel circuit, $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \ldots..$

output voltage across $R_1 = \left(\dfrac{R_1}{R_1 + R_2}\right) \times$ input voltage

Waves and Nuclear Physics Formulae

fringe spacing $= \dfrac{\lambda D}{d}$

single slit diffraction minimum $\sin\theta = \dfrac{\lambda}{b}$

diffraction grating $n\lambda = d\sin\theta$

Doppler shift $\dfrac{\Delta f}{f} = \dfrac{v}{c}$ for $v << c$

Hubble law $v = Hd$

radioactive decay $A = \lambda N$

Properties of Quarks

Type of quark	Charge	Baryon number
up u	$+\frac{2}{3}e$	$+\frac{1}{3}$
down d	$-\frac{1}{3}e$	$+\frac{1}{3}$
$\overline{u}$	$-\frac{2}{3}e$	$-\frac{1}{3}$
$\overline{d}$	$+\frac{1}{3}e$	$-\frac{1}{3}$

Lepton Numbers

Particle	Lepton number L		
	L_e	L_μ	L_τ
e^-	1		
e^+	−1		
ν_e	1		
$\overline{\nu}_e$	−1		
μ^-		1	
μ^+		−1	
ν_μ		1	
$\overline{\nu}_\mu$		−1	
τ^-			1
τ^+			−1
ν_τ			1
$\overline{\nu}_\tau$			−1

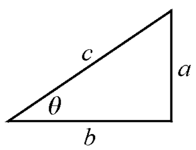
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

area of a circle $= \pi r^2$

surface area of sphere $= 4\pi r^2$

volume of sphere $= \frac{4}{3}\pi r^3$



$\sin\theta = \dfrac{a}{c}$

$\cos\theta = \dfrac{b}{c}$

$\tan\theta = \dfrac{a}{b}$

$c^2 = a^2 + b^2$

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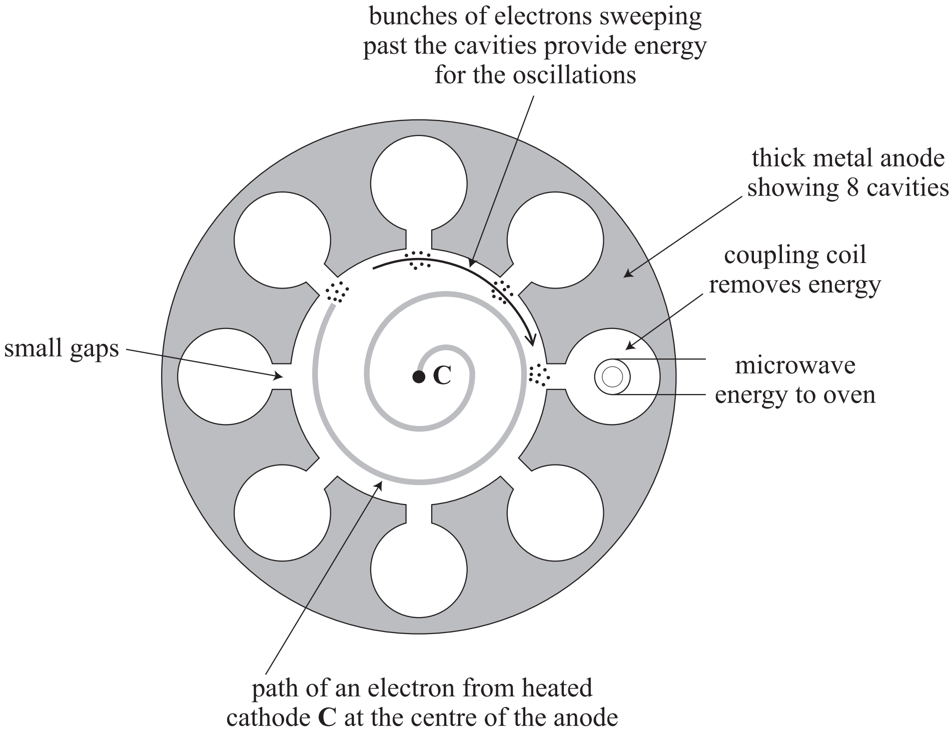
Microwave Ovens

The passage printed on pages 2 and 3 of this loose insert is for answering Questions 6, 7, 8, 9, 10 and 11.

Microwave ovens are now used in many homes and restaurants. The microwaves in an oven are produced by a magnetron such as that shown schematically in **Figure A**.

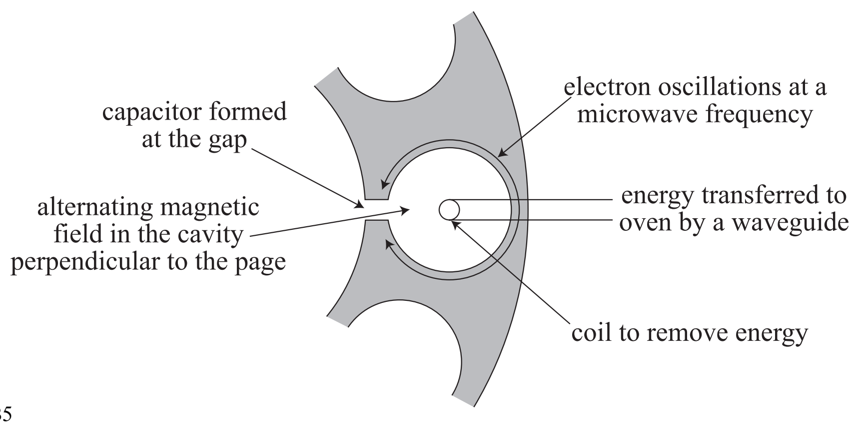
Figure A



The heated cathode, **C**, is at the centre of the anode which is a ring of metal a few mm thick. This ring has a number of circular holes cut in it with small gaps as shown in **Figure A**. These holes are called cavities.

Electrons produced at the cathode **C** are accelerated towards the positive anode in the radial electric field produced by a potential difference of 4000 V. At the same time a magnetic field, perpendicular to the diagram in **Figure A**, causes the electrons to move in a spiral path which increases in radius as they move outwards. When the electrons reach the anode they are moving in a circular path of radius 30 mm. The arrangement causes the electrons to move in 'bunches' and, as each bunch passes a cavity gap, energy is transferred to the cavity. This action makes electrons in the anode oscillate around each cavity setting up alternating magnetic fields in the cavities. **Figure B** shows the direction of the oscillations for one of the cavities.

Figure B

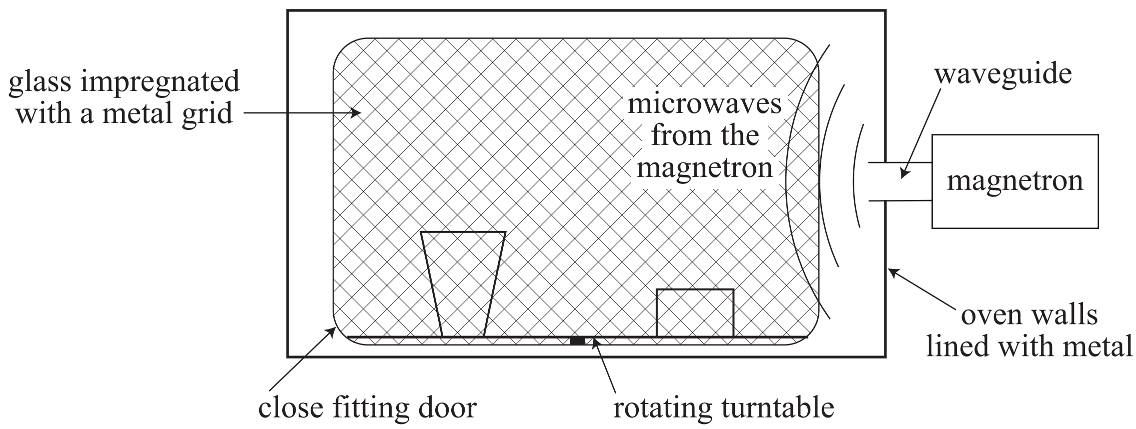


The energy stored in a cavity alternates between the magnetic field in the cavity and the electric field in the capacitor formed at the gap. The total energy builds up as each cavity resonates. The resonant frequency of the magnetron is determined by the radius of the cavity and the dimensions of the gap.

The energy is extracted due to 'transformer action' in a coupling coil in one of the cavities. This coil behaves like the secondary of a transformer and is shown in **Figure A** and **Figure B**. The coil is connected to a short aerial which transmits microwaves through a waveguide into the oven. The microwaves in an oven have a frequency of about 2450 MHz. A typical oven has an input power of 1500 W of which 1100 W is converted to microwave energy. Some energy is used to rotate the food on a turntable and some is lost in heating internal parts of the oven and the surroundings.

Figure C shows a cross-section through a microwave oven.

Figure C



The inside of the oven is lined with metal which reflects the waves and the microwave photons transfer energy to the water in the food being cooked. The design of the oven has to take account of the fact that standing waves can be set up inside the oven which could mean that some parts of the food being cooked would receive no energy at all. The rotating turntable can minimise this effect. Microwaves are dangerous and can also affect radio and TV reception so designers have to ensure that the intensity of any escaping microwaves is at a safe level.

Microwaves photons pass on energy to water molecules. This increases the temperature of the water in the food which results in the food being cooked. Microwave intensity decreases exponentially with distance travelled in the food so that only the outer parts of the food are cooked directly by the microwaves. Heat transferred from the outer parts cooks the inner region so that the procedure requires some 'waiting time' during cooking and before serving to ensure that cooking is complete although this is less necessary when heating liquids.

Data required when answering questions

Planck constant	=	6.7×10^{-34} J s
speed of electromagnetic radiation	=	3.0×10^{8} m s^{-1}
electron charge	=	-1.6×10^{-19} C
electron mass	=	9.1×10^{-31} kg

Turn over ▸

Circular Motion and Oscillations

$$v = r\omega$$

$$a = -(2\pi f)^2 x$$

$$x = A \cos 2\pi f t$$

$$\text{maximum } a = (2\pi f)^2 A$$

$$\text{maximum } v = 2\pi f A$$

$$\text{for a mass-spring system, } T = 2\pi\sqrt{\frac{m}{k}}$$

$$\text{for a simple pendulum, } T = 2\pi\sqrt{\frac{l}{g}}$$

Fields and their Applications

$$\text{uniform electric field strength, } E = \frac{V}{d} = \frac{F}{Q}$$

$$\text{for a radial field, } E = \frac{kQ}{r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

$$g = \frac{F}{m}$$

$$g = \frac{GM}{r^2}$$

$$\text{for point masses, } \Delta E_p = GM_1M_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\text{for point charges, } \Delta E_p = kQ_1Q_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\text{for a straight wire, } F = BIl$$

$$\text{for a moving charge, } F = BQv$$

$$\phi = BA$$

$$\text{induced emf} = \frac{\Delta(N\phi)}{t}$$

$$E = mc^2$$

Temperature and Molecular Kinetic Theory

$$T/\text{K} = \frac{(pV)_T}{(pV)_{tr}} \times 273.16$$

$$pV = \tfrac{1}{3} Nm\langle c^2\rangle$$

$$\text{energy of a molecule} = \tfrac{3}{2} kT$$

Heating and Working

$$\Delta U = Q + W$$

$$Q = mc\Delta\theta$$

$$Q = ml$$

$$P = Fv$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{power input}}$$

$$\text{work done on gas} = p\Delta V$$

$$\text{work done on a solid} = \tfrac{1}{2} F\Delta l$$

$$\text{stress} = \frac{F}{A}$$

$$\text{strain} = \frac{\Delta l}{l}$$

$$\text{Young modulus} = \frac{\text{stress}}{\text{strain}}$$

Capacitance and Exponential Change

$$\text{in series, } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\text{in parallel, } C = C_1 + C_2$$

$$\text{energy stored by capacitor} = \tfrac{1}{2} QV$$

$$\text{parallel plate capacitance, } C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

$$Q = Q_0 e^{-t/RC}$$

$$\text{time constant} = RC$$

$$\text{time to halve} = 0.69\, RC$$

$$N = N_0 e^{-\lambda t}$$

$$A = A_0 e^{-\lambda t}$$

$$\text{half-life, } t_{\frac{1}{2}} = \frac{0.69}{\lambda}$$

Momentum and Quantum Phenomena

$$Ft = \Delta(mv)$$

$$E = hf$$

$$hf = \Phi + E_{k(max)}$$

$$hf = E_2 - E_1$$

$$\lambda = \frac{h}{mv}$$