WJEC EDUQAS A-LEVEL PHYSICS · COMPONENT 3

PHYSICS



EXAM QUESTION PACK

OPTION B: MEDICAL PHYSICS

SCORE	PERCENTAGE
/80	%

STEMUP

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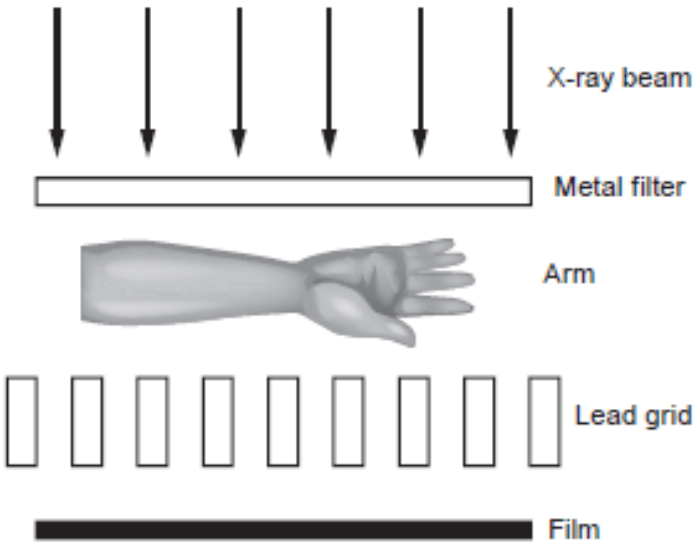
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#1

12. *(a)* When taking an X-ray image of a person's arm a metal filter is placed between the X-ray tube and the arm, and a lead grid between the arm and the film as shown.



Explain the purpose of both the metal filter and the lead grid. [4]

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(b) An X-ray tube operates at a pd of 30 kV producing a tube current of 15 mA.

(i) Calculate the number of electrons that strike the target element every second. [2]

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(ii) Calculate the force exerted by the electron beam on the target. [3]

(c) You have the choice of the following forms of medical imaging available:

MRI scan **PET scan** **ultrasound B-scan** **CT scan**

Evaluate the effectiveness of each type of imaging in detecting a cancerous tumour on a person's lung. [5]

(d) (i) Radioactive tracers can be used to measure the volume of blood in a patient. Describe one other use of radioactive tracers naming the part of the body they are diagnosing. [1]

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(ii) An isotope of sodium, Na-24, has a half-life of 15 hours and an initial activity of 160 Bq when injected into a patient. Seven hours later a sample of 5 cm^3 of blood was taken and found to have an activity of 0.12 Bq. Estimate the volume of blood in the patient. [3]

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(iii) Ultrasound of frequency 3.0 MHz was used to measure the rate of flow of blood. A shift of 0.50 kHz was detected. The measurement was taken at an angle of 30° to the direction of flow and the speed of ultrasound through the blood is 1 500 $m\,s^{-1}$. Calculate the speed of blood flow. [2]

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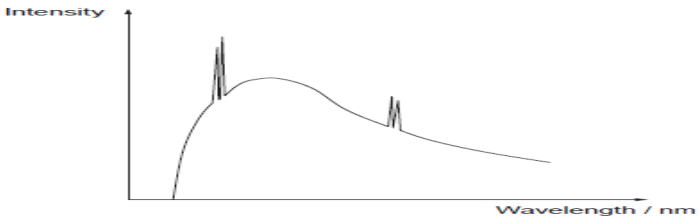
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Question taken from Eduqas examination paper 842103, June 2018

#2

(a) The graph below shows the intensity spectrum for an X-ray tube.



(i) **Draw on the above diagram** an intensity spectrum for the same X-ray tube with a **higher** operating voltage. [1]

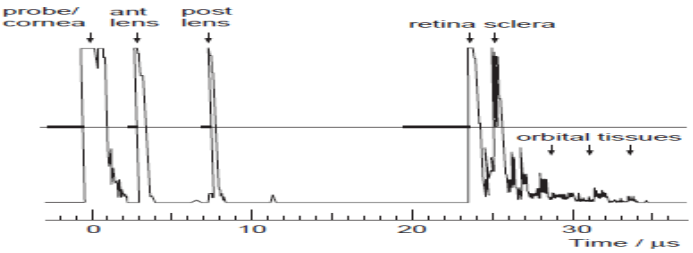
(ii) If the operating voltage of the tube is 30 000 V, determine the minimum wavelength of the X-rays produced. [2]

(iii) If the anode current is 120 mA and the X-ray tube has an efficiency of 0.450 % calculate the rate of production of heat at the anode. [2]

(iv) Explain whether it would be possible to reduce the minimum wavelength to zero. [1]

(b) (i) An ultrasound probe (A scan) can be used to determine the thickness of a lens in the human eye. Explain how a piezoelectric transducer can be used to produce ultrasound. [2]

(ii) A typical ultrasound A scan used to determine the thickness of a lens is given in the diagram below. The spike labelled 'ant lens' corresponds to the front of the lens and the spike labelled 'post lens' corresponds to the back of the lens.



Use the information in the diagram to calculate the lens thickness. The speed of ultrasound in the lens is 1640 m s^{-1}. [3]

(c) You have the choice of the following forms of medical imaging:

X-ray **ultrasound A scan** **radioactive tracer** **CT scan**

Justifying the reasons for your answer, state which of the above you would use to detect the following:

(i) A cerebral haemorrhage (bleed in the brain). [3]

(ii) An underactive thyroid gland. [2]

(d) An MRI (magnetic resonance imaging) scanner has a magnetic field that varies from 0.80 T to 1.40 T along its length. Calculate the wavelength of electromagnetic waves required to scan a slice halfway along its length **and** state which part of the electromagnetic spectrum they belong to. [4]

Question taken from Eduqas examination paper 842103, November 2020

#3

(a) Describe briefly how X-rays are produced in an X-ray tube. [2]

(b) (i) When a beam of X-rays passes through bone the X-rays are absorbed and the beam becomes attenuated. The thickness of bone needed to reduce the original intensity by 50 % is known as the half value thickness, $x_{\frac{1}{2}}$. Show that $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$ where μ is the attenuation coefficient. [3]

(ii) A beam of X-rays is used to detect a fracture in a bone. If the half value thickness for these X-rays in bone is 1.5 cm, calculate the thickness of bone that reduces the incident intensity by 60 % of the original intensity. [3]

(iii) X-ray imaging is not suitable for diagnosing brain tumours. Explain why, and suggest a more suitable technique giving your reasons. [3]

(c) An ultrasound probe can be used to check the development of an unborn baby. Explain how a piezoelectric transducer can be used to produce ultrasound. [2]

(d) The table below gives some ultrasound properties of different body tissues.

Material	Density / kg m^{-3}	Velocity / m s^{-1}	Acoustic impedance / kg m^{-2} s^{-1}
Muscle	1 075	1 590	
Fat	925	1 450	
Bone	1 908	4 080	

(i) **Complete the table** by calculating the different values for acoustic impedance. [2]

(ii) The fraction of ultrasound reflected at a boundary is given by the reflection coefficient, R, where:

$$R = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

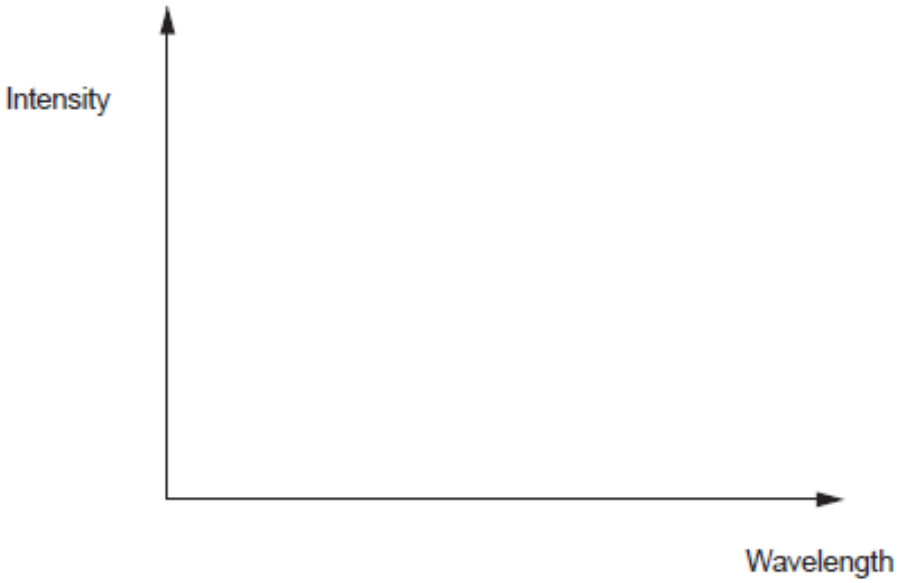
Between which **two** tissues would the greatest amount of ultrasound be reflected? Justify your answer numerically. [3]

(e) A typical MRI scanner operates with a Larmor frequency of 64 MHz. Calculate the magnetic field strength, B, that would be needed to provide this, and state which patients would **not** be able to undergo MRI scans. [2]

Question taken from Eduqas examination paper 842103, June 2017

#4

12. *(a)* (i) Sketch graphs to show how the intensity of X-rays from an X-ray tube varies with wavelength for a tube operating at two different voltages. Label the main features of the graphs and indicate which curve represents the higher voltage. [4]



(ii) The lower voltage tube operates at 20 kV. Determine the velocity with which the electrons strike the target. [2]

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(iii) Calculate the minimum wavelength of the X-ray photons produced by these electrons. [2]

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(b) (i) Ultrasound can be used to carry out either an amplitude scan (A-scan) or a brightness scan (B-scan). Explain which of these two methods you would use to determine the depth of the tumour. Justify your answer. [2]

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(ii) An ultrasound scan can be used to indicate the thickness of fat on a person's body. Typically fat has a density of $930\,kg\,m^{-3}$ and an acoustic impedance of $1.35 \times 10^{6}\,kg\,m^{-2}\,s^{-1}$. If the time delay for the ultrasound pulse is 0.040 ms. Determine the thickness of fat. [3]

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(c) (i) Explain two properties of a radioactive isotope used as a tracer in medicine. [2]

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(ii) A small volume of Human Serum Albumin (HSA) labelled with iodine-125 of activity 160 Bq is injected into the bloodstream of a patient. A sample of 0.8 cm^3 of blood was taken a few hours later and was found to have an activity of 0.025 Bq. If the half-life of iodine-125 is 60 days, calculate the volume of blood in the patient. State any assumptions you make. [3]

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(d) In a magnetic resonance imaging (MRI) scanner a large magnetic field of 1.5 T is used along with short pulses of radio waves. Dr Francis suggests that radio waves of wavelength approximately 5 m would be suitable for this MRI scanner. Determine whether or not Dr Francis is correct. [2]

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Question taken from Eduqas examination paper 842103, June 2019

Marking Scheme

#1

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
12	*(a)*		Metal filter to remove low energy X-rays (1) So they are not absorbed by tissue causing damage (1) Lead grid to absorb scattered X-rays (1) to increase contrast / reduce shadow areas (1)	4			4		
	(b)	(i)	$Q = It$ / current is charge per second (1) no of electrons per second = $\frac{0.015}{1.6 \times 10^{-19}} = 9.4 \times 10^{16}$ (1)	1	1		2	2	
		(ii)	**Either:** Application of $eV = \frac{1}{2} mv^2$ (1) $v = 1.03 \times 10^8$ m s^{-1} (1) $F = mv \times$ no of electrons per sec = 8.79×10^{-6} [N] (1) **Or:** Application of $p = \sqrt{2mE_k}$ (1) Electron momentum = 9.35×10^{-23} N s (1) $F = p \times$ no. of electrons per second = 8.79×10^{-6} [N] (1)		3		3	3	
	(c)		MRI works and non ionising/time consuming/expensive-ish (1) (£500) PET works but ionising/expensive/limited availability/low resolution (1) (£900) Ultrasound B won't work/too much air reflection (1) (£150) CT works but ionising/expensive-ish (1) (£500) Conclusion all work except ultrasound but MRI best (1)			5	5		
	(d)	(i)	Kidney to check flow / Thyroid to check uptake (of iodine)/blood flow through the brain check for blockages /any other example	1			1		
		(ii)	$\frac{0.12}{5} = 0.024$ [Bq cm^{-3}] (1) Activity $= 160e^{(-0.0462 \times 7)}$ [or $160 \times 2^{-\frac{7}{15}}$] $= 115.8$ or 116 [Bq] (1) Volume $(\frac{115.8}{0.024}) = 4825$ cm^3 (1)		3		3	3	
		(iii)	Rearrangement $v = \frac{\Delta f_c}{2 f_0 \cos\theta}$ (1) $v = 0.14$[4] m s^{-1} (1)		2		2	2	
			Question 12 total	**6**	**9**	**5**	**20**	**10**	**0**

#2

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
	(a)	(i)	Curve identical to the original (including the line spectrum in the same place) but all the curve above the original with the minimum wavelength below original but not at (0,0)		1		1		
		(ii)	Use of $eV = \frac{hc}{\lambda}$ (1) $\lambda = 4.125 \times 10^{-11}$ [m] (1)	1	1		2	2	
		(iii)	Power = $120 \times 10^{-3} \times 30\,000$ (1) Heat production = $(0.9955 \times 3\,600) = 3\,583.8$ or 3 584 [W] (1)	1	1		2	2	
		(iv)	[No] for λ to be zero the voltage must be infinite (all other parts of the expression are constants) / It would require an infinite amount of energy		1		1		
	(b)	(i)	A high freq changing / alternating [electrical] voltage (1) causes the piezoelectric [crystal] to oscillate [producing ultrasound] (1)	2			2		
		(ii)	Time from scale 4.5 ± 0.5 [μs] (1) Distance = $4.5 \times 10^{-6} \times 1\,640 = 7.4 \times 10^{-3}$ [m] (1) Thickness = 3.7×10^{-3} [m] **ecf** (1)		3		3	3	
	(c)	(i)	CT scan (1) Gives a 3D image (1) In real time/only seconds of delay time (1) **Alternative for last 2 marks** A scan will only measure distance **and** tracers will not detect leaks (1) X-rays 2D **and** not in real time (1) (also poor quality for brain)			3	3		
		(ii)	Radioactive tracer (1) Taken up by the thyroid /detected using a gamma camera (1) **Alternative for the last mark** X-ray, CT and A scan will (only) detect the gland (1)			2	2		
	(d)		At centre B = $\frac{(0.80 + 1.40)}{2}$ **OR** 1.10 [T] (1) $f = 42.6 \times 10^6 \times 1.1 = 46.86 \times 10^6$ [Hz] (1) allow **ecf** $\lambda = \frac{3 \times 10^8}{46.86 \times 10^6} = 6.4$ m with units (1) allow **ecf** Radio waves (1)	1 1	 1 1 	 	 4	 3	
			Question total	**6**	**9**	**5**	**20**	**10**	**0**

#3

Question			Marking details	Marks available AO1	AO2	AO3	Total	Maths	Prac
	(a)		Electrons accelerated through a pd (in a vacuum) (1) Collide with target (or anode) / decelerated by target (or nucleus) (1)	2			2		
	(b)	(i)	$\frac{I}{I_0} = \frac{1}{2}$ or $I = I_0 e^{-\mu x}$ (1) $2 = \frac{e^{\mu x}}{\frac{1}{2}} = e^{-\mu x}$ or $\frac{1}{2} = e^{-\mu x}$ (1) $\ln 2 = \mu x$ (1) If negative sign lost for no reason deduct 1 mark	1	1 1		3	3	
		(ii)	$\mu = \frac{\ln 2}{1.5}$ so μ = 0.46(2) or 46.2 (1) $\ln(\frac{100}{40}) = 0.46\,x$ **ecf** (1) x = 2 (.0) cm **with units** (1) **Alternative:** $0.5 = e^{-\mu x\,1.5}$ and $0.4 = e^{-\mu x}$ (1) $\mu = \frac{\ln 0.5}{1.5}$ and $\mu = \frac{\ln 0.4}{x}$ (1) $x = 1.5 \text{x} \frac{\ln 0.4}{\ln 0.5}$ x = 2(.0) cm **with units** (1) Answer of 1.1 award 2 marks If orders of magnitude incorrect award 1 mark maximum $\ln 0.4 = -\mu x$ (1)		3		3	3	
		(iii)	X-rays absorbed by skull / bone (1) MRI / PET (1) High quality images of *soft tissue* (1) or opposite statement i.e. X-rays poor soft tissue contrast	1		1 1	3		
	(c)		Alternating voltage or current applied (1) Crystal vibrates / resonates (1) don't accept just expands and contracts	2			2		
	(d)	(i)	1.71×10^6 1.34×10^6 7.78×10^6 Any 1 correct (1) All three correct (2)		2		2	2	
		(ii)	Must select bone as by far the largest (1) Bone and fat as difference biggest (1) Value calculated as 0.5 (1)		1	1 1	3	1	
	(e)		1.5 T **with units** (1) Patients with any metal in their bodies / pacemakers (1) (accept claustrophobic/young children need general anaesthetic)		1	1	2	1	
			Question total	**6**	**9**	**5**	**20**	**10**	**0**

#4

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
12	*(a)*	(i)	Two graphs with skewed normal distributions one always above the other labelled background or continuous [spectra] (1) Line spectra shown on both graphs in the same place and labelled (1) Minimum wavelengths labelled and not at (0,0) and not meeting at the x-axis (1) Higher curve labelled higher voltage (1)	4			4		
		(ii)	$v = \sqrt{\frac{2eV}{m}}$ (1) v = 8.38 [or 8.4] × 10^7 [m s^{-1}] (1)		2		2	2	
		(iii)	$\lambda = \frac{hc}{eV}$ (1) λ = 6.22 × 10^{-11} [m] (1)		2		2	2	
	(b)	(i)	A-scans / amplitude scans (1) Only needed to measure depth / moving images not needed (1)			2	2		
		(ii)	Speed in fat / c = 1 450 [m s^{-1}] (1) Distance travelled = 1 450 × 0.04 × 10^{-3} = 0.058 [m] or 5.8 [cm] (1) Thickness of fat = $\frac{0.058}{2}$ = 0.029 [m] or 2.9 [cm] or 0.03 [m] **ecf** (1)		3		3	2	
	(c)	(i)	Short half-life [hence small dose] (1) Gamma emitter & less ionising/more penetrating (1)	2			2		
		(ii)	Activity will not change [in a short time] / half-life too long for activity to change / uniform mixing in blood (1) [Dilution factor] = $\frac{160}{0.025}$ or 6 400 (1) [Volume = 6 400 × 0.8] = 5 120 cm^3] (1)		1 1	1	3	2	
	(d)		They need to precess so $f = \frac{42.6 \times 10^6 \times 1.5}{6.39 \times 10^7}$ [=6.39 × 10^7 Hz] (1) Wavelength = $\frac{3 \times 10^8}{6.39 \times 10^7}$ = 4.7 [m], so [Dr Francis] correct (1) Accept incorrect as 4.7 [m] is not equal to 5.0 [m] **Alternative:** Two frequencies compared with a correct conclusion			2	2	2	
			Question 12 total	**6**	**9**	**5**	**20**	**10**	**0**