CAMBRIDGE INTERNATIONAL A LEVEL • PHYSICS 9702

Topical Questions

Unit 24: Medical Physics

Past Papers 2021 – 2025

MARK SCHEME 26 Questions

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Question 1 — Mark Scheme

Question	Answer	Marks
11(a)(i)	ease with which edges can be distinguished	**B1**
11(a)(ii)	difference in degrees of blackening	**B1**
11(b)	$I = I_0 \exp(-\mu x)$	**C1**
	$0.12 = \exp(-\mu \times 2.3)$ $\ln 0.12 = -2.3 \times \mu$	**C1**
	$\mu = 0.92\ \text{cm}^{-1}$	**A1**
11(c)	advantage: produces 3-dimensional image	**B1**
	disadvantage: (much) greater exposure to radiation	**B1**

Question 2 — Mark Scheme

Question	Answer	Marks
12(a)	probability of decay (of a nucleus)	M1
	per unit time	A1
12(b)	$A = \lambda N$	C1
	N = mass / (nucleon number × u)	C1
	$2.92 \times 10^{9} = (\lambda \times 5.87 \times 10^{-10}) / (131 \times 1.66 \times 10^{-27})$ $\lambda = 1.08 \times 10^{-6}\ s^{-1}$	A1
12(c)	• sample emits radiation in all directions • some radiation is absorbed by air/detector window • self-absorption within the source • dead time/inefficiency of detector *Any two points, 1 mark each*	B2

Question 3 — Mark Scheme

Question	Answer	Marks
11(a)	generates ultrasound	B1
	detects reflected ultrasound	B1
	applied p.d. causes crystal to vibrate **or** vibrations cause crystal to generate an e.m.f.	B1
11(b)(i)	product of density and speed	M1
	speed of ultrasound in medium	A1
11(b)(ii)	difference between (the specific acoustic impedances)	C1
	• if similar/same then reflection coefficient is zero/very low • if very different then reflection coefficient is (nearly) 1 • the lower the difference means lower the reflection coefficient (*any one point*)	A1

Question 4 — Mark Scheme

Question	Answer	Marks
11(a)	intensity: vary filament current/p.d. across filament	**B1**
	hardness: vary accelerating potential difference	**B1**
11(b)(i)	$I = I_0 e^{-\mu x}$	**C1**
	$I_S = I_0 \exp(-0.92 \times 9.0)$ $= 2.5 \times 10^{-4} I_0$	**A1**
11(b)(ii)	$I_C = [\exp(-0.92 \times 6.0) \times \exp(-2.9 \times 3.0)] I_0$	**C1**
	$= 6.7 \times 10^{-7} I_0$	**A1**
11(c)	conclusion consistent with values in **(b)(i)** and **(b)(ii)** e.g. $I_S \gg I_C$ so good contrast	**B1**

Question 5 — Mark Scheme

Question	Answer	Marks
11(a)	to produce a 3-dimensional image of structure/body	**B1**
11(b)	X-rays (are used)	**B1**
	scanning in sections	**B1**
	scanning from many angles	**B1**
	image of each section is 2-dimensional	**B1**
	scanning repeated for many sections **or** images of many sections combined together	**B1**

Question 6 — Mark Scheme

Question	Answer	Marks
11(a)(i)	electrons decelerate (on hitting target) so X-ray photons produced	B1
	range of decelerations	B1
	photon energy depends on (magnitude of) deceleration	B1
11(a)(ii)	$eV = \frac{hc}{\lambda}$	C1
	$\lambda = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{1.6\times10^{-19}\times15000}$	C1
	$= 8.3\times10^{-11} m$	A1
	or $E = hf$ and $c = f\lambda$ and electron energy = eV *or* $E = hc / \lambda$ and electron energy = eV electron energy = $1.6 \times 10^{-19} \times 15000$ $= 2.4 \times 10^{-15}$	(C1)
	$\lambda = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.4\times10^{-15}}$	(C1)
	$\lambda = 8.3\times10^{-11} m$	(A1)
11(b)(i)	μ = – gradient *or* $\ln (I / I_o) = -\mu x$	C1
	(e.g. 2.08 / 10.0) = **0.21** cm^{-1}	A1

Question	Answer	Marks
11(b)(ii)	$\ln(0.05) = -\mu x$	C1
	$x = \frac{\ln 0.05}{-\mu}$ $e.g.\ x = 14\,cm$	A1

Question 7 — Mark Scheme

Question	Answer	Marks
10(a)	energy = mcΔT	C1
	energy = ItV $(\Delta T =) \frac{0.40 \times 0.020 \times 75\,000 \times 0.95}{0.015 \times 130}$	C1
	=290 K	A1
10(b)	$I = I_o e^{-\mu t}$ $0.20 = e^{-0.22t}$	C1
	t = 7.3 cm	A1

Question 8 — Mark Scheme

Question	Answer	Marks
11(a)	substance containing radioactive nuclei that is introduced into the body *or* substance containing radioactive nuclei that is absorbed by the tissue being studied	**B1**
11(b)(i)	a particle interacting with its antiparticle so that mass is converted into energy	**B1**
11(b)(ii)	electron(s) and positron(s)	**B1**
11(c)(i)	$E = 2mc^2$ $= 2\times9.11\times10^{-31}\times3.00\times10^{-82}$ $= 1.64\times10^{-13}$J	**A1**

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Question	Answer	Marks
11(c)(ii)	$\lambda = \frac{2hc}{E}$ $= \frac{2\times6.63\times10^{-34}\times3.00\times10^{8}}{1.64\times10^{-13}}$	**C1**
	$= 2.43\times 10^{-12}$ m	**A1**
11(d)	Any 3 from: • the two gamma photons travel in opposite directions • gamma photons detected (outside body / by detectors) • gamma photons arrive (at detector) at different times • determine location of production (of gamma)	**B3**

Question 9 — Mark Scheme

9702/41 Cambridge International AS & A Level – Mark Scheme **PUBLISHED** May/June 2022

Question	Answer	Marks
9(a)(i)	electrons are accelerated (by an applied p.d.)	**B1**
	electrons hit target	**B1**
	X-rays produced when electrons decelerate	**B1**
9(a)(ii)	images of the multiple sections are combined to create a 3-D image	**B1**
9(b)(i)	$I = I_0 \exp(-\mu x)$	**C1**
	$= I_0 \exp(-0.89 \times 5.6)$ $= 0.0068\ I_0$	**A1**
9(b)(ii)	$I = I_0 \exp(-2.4 \times 3.4) \times \exp(-0.89 \times 3.2)$	**C1**
	$= 1.7 \times 10^{-5}\ I_0$	**A1**
9(c)	comparison of intensities or values in **(b)** leading to conclusion consistent with these values	**B1**

Question 10 — Mark Scheme

Question	Answer	Marks
7(a)(i)	peak voltage = $4.2 \times \sqrt{2}$ (= 5.9 V)	**B1**
	power = V^2 / R = $5.9^2 / 760$ = 0.046 W or 46 mW	**A1**
7(a)(ii)	sketch shows peak(s) in power at 46 mW	**B1**
	correct shape (sinusoidal wave sitting on *t*-axis)	**B1**
	four cycles of repeating pattern shown, with P = 0 at 0, 10, 20, 30, 40 μs	**B1**
7(a)(iii)	line is symmetrical about 23 mW	**B1**
7(b)(i)	(alternating p.d. makes) the crystal vibrate	**B1**
	vibrations (of crystal) causes air to vibrate	**B1**
	frequency is in ultrasound range	**B1**
7(b)(ii)	(air makes) crystal vibrate, which causes an e.m.f. to be generated across the (second) crystal	**B1**

Question 11 — Mark Scheme

Question	Answer	Marks
9(a)	piezo-electric crystal	**B1**
	(ultrasound) wave causes shape change / vibrations (of crystal)	**B1**
	shape change / vibrations causes e.m.f. (which is detected)	**B1**
9(b)(i)	93 V	**A1**
9(b)(ii)	$2.7 \times 10^{7}\,\text{rad s}^{-1}$	**A1**
9(c)(i)	$\text{kg m}^{-2}\text{s}^{-1}$	**B1**
9(c)(ii)	$\rho = Z / c = 1.7 \times 10^{6} / 1600$ $= 1100\,\text{kg m}^{-3}$	**A1**
9(c)(iii)	intensity reflection coefficient ≈ 1 **or** Z_1 and Z_2 are very different	**B1**
	almost no / no ultrasound transmitted (into air filled cavity)	**B1**

Question 12 — Mark Scheme

Question	Answer	Marks
8(a)(i)	specific acoustic impedance = $1200 \times 1400 = 1.68 \times 10^6$ kg m^{-2} s^{-1}	**A1**
8(a)(ii)	density of air shown in table as 1.29	**A1**
	speed of sound in tissue shown in table as 1540	**A1**
8(b)(i)	intensity reflection coefficient = $(Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$ $= (1680000 - 440)^2 / (1680000 + 440)^2$	**C1**
	$= 0.999$	**A1**
8(b)(ii)	intensity reflection coefficient $= (Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$ $= (1680000 - 1680000)^2 / (1680000 + 1680000)^2$ $= 0$	**A1**
8(c)	without gel, (almost) all of the (incident) ultrasound is reflected (from skin)	**B1**
	with gel, (almost) all of the (incident) ultrasound is transmitted (into the body)	**B1**

Question 13 — Mark Scheme

Question	Answer	Marks
10(a)(i)	electrons	B1
10(a)(ii)	electrons are decelerated / stopped on impact with the target	B1
	(kinetic) energy lost by electrons emitted as (X-ray) photons	B1
10(a)(iii)	$eV = hc / \lambda$	C1
	$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (1.60 \times 10^{-19} \times 5800)$	C1
	$= 2.14 \times 10^{-10}$ m	A1
10(b)	$I = I_0 \exp(-\mu x)$	C1
	$I_T / I_0 = \exp(-(1.4 \times 2.8))$ $= 0.020$	C1
	% absorbed $= (1.000 - 0.0198) \times 100$ $= 98\%$	A1

Question 14 — Mark Scheme

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Question	Answer	Marks
10(a)	ultrasound production: vibrating quartz crystal	B1
	X-ray production: electrons hitting metal target	B1
	ultrasound detected wave: reflected	B1
	X-ray detected wave: transmitted	B1
10(b)(i)	$I = I_0 \exp(-\mu x)$	C1
	$\ln(0.72) = -6.2\mu$ $\mu = 0.053\ \text{cm}^{-1}$	A1
10(b)(ii)	$I / I_0 = \exp(-9.3 \times 0.053)$ $(= 0.61)$	C1
	percentage attenuated $= 100 \times (1.00 - 0.61)$ $= 39\%$	A1

Question 15 — Mark Scheme

Question	Answer	Marks
9(a)(i)	material introduced into the body **and** (position in body) can be detected **or** absorbed by the tissue (being studied)	**B1**
9(a)(ii)	X = β^+ **or** e^+ **and** $P = 1$	**B1**
	$Q = 0$ **and** $R = 18$	**B1**
9(b)(i)	positrons (emitted in the decay) and electrons annihilate	**B1**
	mass of particles becomes energy of gamma photons	**B1**
9(b)(ii)	arrival times of photons are processed	**B1**
	image built up of tracer concentration in the tissue	**B1**
9(c)(i)	$A = \lambda N$ **and** $\lambda = \ln 2 / T$	**C1**
	$N = n \times N_A$	**C1**
	2 photons produced from each decay, so $R_0 = 2 \times \lambda \times n \times N_A$ $R_0 = (2 \ln 2)\, nN_A / T$ (*allow 0.693 for ln 2*)	**A1**
9(c)(ii)	sketch: exponential decay curve from $t = 0$ to $t = 2T$, starting at $(0, R_0)$ and with a negative gradient of continuously decreasing magnitude	**B1**
	line with negative gradient passing through $(T, R_0/2)$ and $(2T, R_0/4)$	**B1**

Question 16 — Mark Scheme

Question	Answer	Marks
9(a)(i)	$eV = hc / \lambda$	C1
	$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (84 \times 10^{3} \times 1.60 \times 10^{-19})$ $= 1.5 \times 10^{-11}$ m	A1
9(a)(ii)	**either** (some) kinetic energy (of electrons) is converted to thermal energy at target **or** some X-rays are absorbed by the target so its temperature increases	B1
	(tungsten) has higher melting point so does not melt quickly / easily	B1

Question	Answer	Marks
9(b)	$I = I_0 \exp(-\mu t)$	C1
	$0.13 = [\exp(-3.0x)] \times [\exp(-0.22x)]$ $= \exp(-3.22x)$	C1
	$x = 0.63$ cm	A1
9(c)(i)	product of density and speed	M1
	speed of ultrasound in medium	A1
9(c)(ii)	$I_R / I_0 = (7.8 - 1.7)^2 / (7.8 + 1.7)^2$ $= 0.41$ fraction transmitted = 1.00 – 0.41 = 0.59	C1
	percentage transmitted = **59%**	A1
9(c)(iii)	more than one boundary so more reflections	B1
	some ultrasound is attenuated in matter	B1

Question 17 — Mark Scheme

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Question	Answer	Marks
8(a)	packet / quantum of energy	M1
	of electromagnetic radiation	A1
8(b)(i)	electron(s)	B1
8(b)(ii)	X labelled – **and** Y labelled +	B1
8(c)(i)	0.032 MeV	A1
8(c)(ii)	momentum = E / c	C1
	momentum = $(0.032 \times 1.60 \times 10^{-13}) / (3.00 \times 10^{8})$ $= 1.7 \times 10^{-23}$ N s	A1
8(c)(iii)	$E = hf$ **and** $\lambda = c / f$	C1
	$\lambda = hc / E$ $= (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (0.032 \times 1.60 \times 10^{-13})$	C1
	$\lambda = 3.9 \times 10^{-11}$ m	A1
8(d)	discussion of bone and soft tissue	B1
	discussion of different attenuation (coefficients) **or** discussion differences in penetration / transmission / absorption	B1
	transmitted intensities (by bone and tissue) are very different (leading to good contrast images)	B1

Question 18 — Mark Scheme

Question	Answer	Marks
10(a)	time gives information about depth (of boundary)	**B1**
	intensity gives information about nature of boundary	**B1**
10(b)(i)	product of density and speed	**M1**
	speed of ultrasound in medium (and density of medium)	**A1**
10(b)(ii)	$Z_{water} = 1000 \times 1420$ ($= 1.42 \times 10^6$ kg m^{-2} s^{-1}) **and** $Z_{glass} = 2500 \times 4560$ ($= 11.4 \times 10^6$ kg m^{-2} s^{-1})	**C1**
	intensity reflection coefficient = $(11.4 - 1.42)^2 / (11.4 + 1.42)^2$	**C1**
	$= 0.61$	**A1**

Question 19 — Mark Scheme

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Question	Answer	Marks
9(b)(i)	• (pair) annihilation occurs • the mass of the two particles is converted into energy • two gamma photons are formed and travel in opposite directions **or** two gamma photons are formed and leave the body • difference in arrival times of photons (at detector) is processed *Any three points, 1 mark each*	**B3**
9(b)(ii)	with a shorter half-life: sample would (almost) fully decay before the test is complete	**B1**
	a longer half-life: exposes patient to harmful/ionising radiation unnecessarily **or** with a longer half-life: a larger dose (of tracer) needed to produce detectable activity	**B1**

Question 20 — Mark Scheme

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Question	Answer	Marks
9(e)(i)	positrons collide with electrons and annihilate	**B1**
9(e)(ii)	long enough to have time to conduct investigation, not so long as to cause patient unnecessary exposure to radiation	**B1**

Question 21 — Mark Scheme

Question	Answer	Marks
8(a)	wavelength associated with a moving particle	**B1**
8(b)	$\lambda = h / p$	**C1**
	$= (6.63 \times 10^{-34}) / (9.11 \times 10^{-31} \times 4.9 \times 10^{7})$ $= 1.5 \times 10^{-11}$ m	**A1**
8(c)	similarity: *any one point from*: • same mass • same magnitude of charge • both leptons	**B1**
	difference: *any one point from*: • electron has negative charge, positron has positive charge • positron is anti-particle of electron • electron is a particle, positron is an anti-particle	**B1**
8(d)(i)	(pair) annihilation	**B1**
8(d)(ii)	their mass gets converted into energy	**B1**
	(their mass–energy) becomes the energy of the gamma photons	**B1**
8(d)(iii)	they travel in opposite directions to conserve momentum	**B1**
8(d)(iv)	kinetic energy = $\frac{1}{2} \times 9.11 \times 10^{-31} \times (4.9 \times 10^{7})^2 = 1.1 \times 10^{-15}$ J	**A1**

Question	Answer	Marks
8(d)(v)	$E = mc^2$	**C1**
	$E = hc / \lambda$ **or** $E = hf$ **and** $c = f\lambda$	**C1**
	$(1.1 \times 10^{-15}) + (9.11 \times 10^{-31} \times (3.00 \times 10^{8})^2) = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / \lambda$ $\lambda = 2.39 \times 10^{-12}$ m	**A1**

Question 22 — Mark Scheme

Question	Answer	Marks
6(a)	plate X marked as negative and plate Y marked as positive	**B1**
6(b)(i)	$E = V / x$	**C1**
	$= (58 \times 10^3) / 0.041$ $= 1.4 \times 10^6$ N C^{-1}	**A1**
6(b)(ii)	$ma = eE$	**C1**
	$a = (1.60 \times 10^{-19} \times 1.41 \times 10^6) / (9.11 \times 10^{-31})$ $= 2.5 \times 10^{17}$ m s^{-2}	**A1**
6(c)(i)	$eV = hc / \lambda$ **or** $eV = hf$ **and** $f = c / \lambda$	**C1**
	$(1.60 \times 10^{-19} \times 58 \times 10^3) = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / \lambda$	**M1**
	clear conversion from m to pm leading to $\lambda = 21$ pm	**A1**
6(c)(ii)	X-rays	**B1**
6(c)(iii)	*Any two points from:* • waves are passed into structure and transmitted waves detected • different parts of the structure absorb different fractions of energy • difference in detected / transmitted intensities used (to form image)	**B2**

Question 23 — Mark Scheme

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Question	Answer	Marks
10(a)	alternating p.d. (applied to crystal) makes crystal vibrate	B1
	when frequency of applied p.d. equals natural frequency of crystal, crystal resonates	B1
	natural frequency of crystal is in ultrasound range	B1
10(b)(i)	product of density and speed	M1
	speed is speed of ultrasound in medium (and density of medium)	A1
10(b)(ii)	(α is close to) 0 when Z_1 and Z_2 are equal	B1
	(α is close to) 1 when Z_1 and Z_2 are very different	B1
10(c)	$I = I_0 \exp(-\mu x)$	C1
	$\ln (I / I_0) = -\mu x$ $\ln 0.62 = -\mu \times 2.1$ $\mu = 0.23\ \text{cm}^{-1}$	A1

Question 24 — Mark Scheme

Question	Answer	Marks
10(a)	product of density and speed	**M1**
	speed of sound in medium (and density of the medium)	**A1**
10(b)	ultrasound waves cause crystal to vibrate	**B1**
	vibrations (of crystal) cause induced e.m.f. (across crystal)	**B1**
10(c)(i)	intensity reflection coefficient= $(40.4 - 1.48)^2 / (40.4 + 1.48)^2$	**C1**
	= 0.86	**A1**
10(c)(ii)	*Z* values are very similar	**B1**
	(almost) all the ultrasound will be transmitted **or** (almost) none of the ultrasound will be reflected	**B1**

Question 25 — Mark Scheme

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	distance found from $F = L / (4\pi d^2)$	B1

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Question	Answer	Marks
10(a)	difference in degrees of blackening	B1
10(b)(i)	$I = I_0 \exp(-\mu x)$ $= I_0 \exp(-5.8 \times 0.35) = 0.13\ I_0$	A1
10(b)(ii)	use of exp {–(0.35 × 3.7)} factor	C1
	$0.053 I_0 = I_0 \exp\{-[(0.35 \times 3.7) + 2.1\mu]\}$	C1
	$\mu = 0.78\ \text{cm}^{-1}$	A1
10(b)(iii)	factor of only 2.5 between the (detected) intensities (so not good contrast)	B1
10(c)	(structure) scanned in (thin) sections	B1
	(many) scans (of each section) taken from different angles	B1
	scanning repeated for all sections and (data) compiled (to form 3D image)	B1

Question 26 — Mark Scheme

Question	Answer	Marks
8(a)	(radioactive) substance introduced into the body	B1
	substance absorbed by the tissues being studied	B1
8(b)(i)	$P = 15$ **and** $R = 0$	A1
	$Q = 7$ **and** $S = (+)1$	A1
8(b)(ii)	(electron) neutrino	B1
8(c)(i)	number of nuclear disintegrations per unit time	B1
8(c)(ii)	decay constant $= \ln 2 / (2.04 \times 60)$	C1
	$= 5.66 \times 10^{-3}\ s^{-1}$	A1
8(c)(iii)	$N = (2.85 \times 10^{-6}) / (15 \times 1.66 \times 10^{-27})$	C1
	$A = \lambda N$	C1
	rate $= (5.66 \times 10^{-3}) \times (2.85 \times 10^{-6}) / (15 \times 1.66 \times 10^{-27})$	C1
	$= 6.48 \times 10^{17}\ s^{-1}$	A1
8(d)(i)	gamma photons	B1
8(d)(ii)	positron collides with electron (in body)	B1
	annihilation results in their masses becoming photon energy	B1

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