Worked Solutions for Sample Examination Questions

Question 1

(a) Both coils have the same area so link the same flux, hence the answer is **A**.

(b)

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = V_p \frac{N_s}{N_p}$$

$$= 400 \text{ V} \times \frac{200 \text{ turns}}{1000 \text{ turns}}$$

$$= 80 \text{ V}.$$

The frequency must be the same at 50 Hz.

Question 2

(a) Rate of change of magnetic flux = $\frac{90 \times 10^{-3} \text{ Wb}}{450 \times 10^{-6} \text{ s}} = 200 \text{ Wb s}^{-1}$.

(b) Induced emf = number of coils x rate of change of flux
so, per coil, the emf = rate of change of flux = 200 V.

Question 3

(a) Flux linking one turn of the coil:

$$\frac{4.0 \times 10^{-4} \text{ Wb turns}}{400 \text{ turns}} = 1.0 \times 10^{-6} \text{ Wb}.$$

(b) Flux density $\Phi = BA$, so

$$B = \frac{\Phi}{A} = \frac{1.0 \times 10^{-6} \text{ Wb}}{1.25 \times 10^{-5} \text{ m}^2} = 8.0 \times 10^{-2}\ T.$$

Question 4

(a) Symbol ϕ or Φ, weber (Wb) ($\phi = B\,A$).

(b) Symbol B, measured in tesla (T) (= ϕ / A).

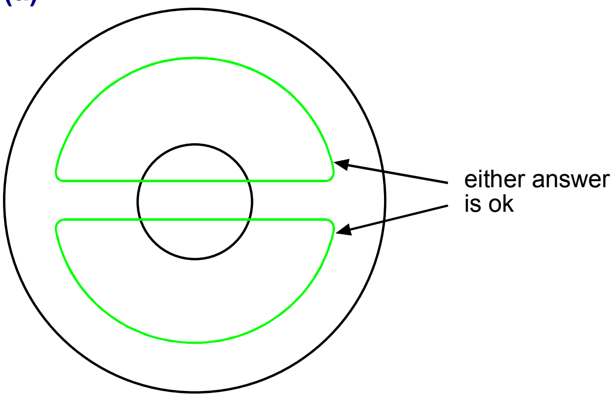
(c) Rate of change of magnetic flux is the emf (Faraday's Law) so it can be measured in volts (V).

Question 5

Rotating twice as fast doubles the frequency to 20 Hz, and cuts flux lines twice as fast so the emf will double to 8 V: therefore the answer is **C**.

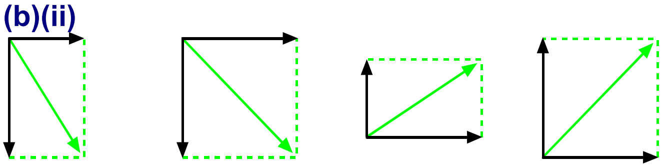
Question 6

(a)



(b)(i) reading from the graph one period = 16 ms. Time difference between the signals = 4 ms = 4/16 = ¼ of a period, which corresponds to 90° or π/2.

(b)(ii)



(b)(iii) The resultant is rotating anticlockwise.

(b)(iv) The changing flux induces an emf in the rotor which sets up a current (an 'eddy current'). The current interacts with the magnetic field to give a force ('$F = I\,L\,B$').

Question 7

$E \approx -\dfrac{dV}{dx}$ so the slope of the graph at r gives the electric field.

Question 8

$F = q\,v\,B = (3.2 \times 10^{-19}\ \text{C}) \times (1.5 \times 10^{7}\ \text{m s}^{-1}) \times 0.25\ \text{T}$
$= 1.2 \times 10^{-12}\ \text{N}.$

Question 9

By definition $V \to 0$ as $d \to \infty$; only graphs A or B fit this fact. A proton has a positive charge, so the answer is B.

Question 10

Field strength = force per unit charge:

$$\begin{aligned} E &= \frac{kQ}{r^2} \\ &= \frac{(8.98\times10^{9}\ \mathrm{N\,C^{-2}\,m^{2}})\times(1.92\times10^{-18}\ \mathrm{C})}{(5.0\times10^{-11}\ \mathrm{m})^2} \\ &= 6.9\times10^{12}\ \mathrm{N\,C^{-1}}. \end{aligned}$$

Question 11

(a) Current = 20 μA = 20 x 10^{-6} A = 20 x 10^{-6} C s^{-1}. Thus:

ions per second = $\dfrac{20\times10^{-6}\ \mathrm{C\,s^{-1}}}{1.6\times10^{-19}\ \mathrm{C\,ion^{-1}}} = 1.3\times10^{14}\ \mathrm{ion\,s^{-1}}$.

(b)(i)

$$E_K = \frac{mv^2}{2}.$$

Therefore the change in E_K is

$$\begin{aligned} \frac{m}{2}[(3.0\times10^{5}\ \mathrm{m\,s^{-1}})^2-(100\ \mathrm{m\,s^{-1}})^2] &= \frac{3.32\times10^{-26}\ \mathrm{kg}}{2}[(9\times10^{10}\ \mathrm{m^2\,s^{-2}})-(1.0\times10^{4}\ \mathrm{m^2\,s^{-2}})] \\ &= 1.49\times10^{-15}\ \mathrm{J}. \end{aligned}$$

(NB: The 1.0 x 10^4 is too small to make any significant difference to the answer.)

(b)(ii) $q\,V$ = 1.49 x 10^{-15} J. Thus

$$V = \frac{1.49\times10^{-15}\ \mathrm{J}}{1.6\times10^{-19}\ \mathrm{C}} = 9.3\ \mathrm{kV}$$

so V must be greater than 5 kV.

(c)(i) The magnetic force is always at right angles to the direction of motion on the ion beam (~current).

(c)(ii) From the diagram the diameter of the circular path = 250 mm, so r = 125 x 10^{-3} m:

$$F = \frac{mv^2}{r} = \frac{(3.32\times10^{-26}\ \text{kg})\times(3.0\times10^{5}\ \text{m s}^{-1})^2}{125\times10^{3}\ \text{m}}$$
$$= 2.39\times10^{-14}\ \text{N}.$$

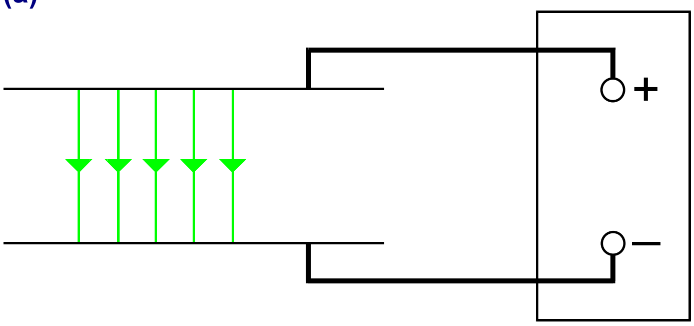
(c)(iii) $F = e\,v\,B$ so

$$B = \frac{F}{ev} = \frac{2.39\times10^{-14}\ \text{N}}{(1.6\times10^{-19}\ \text{C})\times(3.0\times10^{5}\ \text{m s}^{-1})} = 0.49\ \text{T}.$$

(d) Neon-22 has a mass 10% larger than neon-20. Thus for a given accelerating force its final speed will be slower. Thus a lower value of B would be needed to bend it into the same orbit so it will bend with a different radius and not go through the detector slit.

Question 12

(a)



(NB: The question asks for 5 lines: they must be equally spaced because the field is uniform.)

(b) (Note that the set-up is just that for a Millikan's apparatus to find the elementary charge on the electron.) If the sphere does not move the force due to the electric field must act upwards to oppose the sphere's weight due to gravity. If the upper plate is positively charged, the sphere must have a negative charge (unlike charges attract).

(c) $n\,e = 4.8 \times 10^{-14}$ C, so

$$n = \frac{4.8\times10^{-14}\ \text{C}}{1.6\times10^{-19}\ \text{C per electron}} = 3.0\times10^{5}\ \text{electrons}.$$

(NB: The value of e is on the information sheet used in all written exams.)

(d)(i) Force = $q\,E = m\,g$:

$$E = \frac{mg}{q} = \frac{(7.4\times10^{-9}\ \text{kg})\times9.8\ \text{N kg}^{-1}}{4.8\times10^{-14}\ C}$$
$$= 1.5\times10^{6}\ \text{V m}^{-1}\ (\text{or N C}^{-1}).$$

(d)(ii) $E = V / d$, so:

$V = E\,d$ = (1.5 x 10^6 V m^{-1}) x (10 x 10^{-3} m) = 1.5 x 10^4 V (or 15 kV).

(e) Beta radiation will ionize the air molecules. Positive ions will be attracted to the negatively charged sphere thus reducing its negative charge. If the sphere intercepts an actual beta particle it will become more negatively charged.

Question 13

Greater energy means that the proton can get closer to the nucleus because it can climb further up the electrostatic potential energy 'hill'. The distance of closest approach *d* is given by:

$$E_K \approx \frac{qQ}{d}$$

where *q* is the charge on the proton and *Q* the charge on the nucleus, and thus $E_K\,d$ is a constant. If E_K increases, *d* must get smaller.

Question 14

(a) Energy difference for a transition from **D** to **B** = 5.0 eV – 2.5 eV = 2.5 eV.
Thus the energy left with the electron = 3.0 eV – 2.5 eV = 0.5 eV.

(b) A transition to **A** requires 5.0 eV – 1.5 eV = 3.5 eV, which is more than the electron energy, so this transition is impossible.

Question 15

(a)(i) The nucleons are 'close packed' and touching each other like water molecules in a drop of water.

(a)(ii) If volume is proportional to the number of nucleons we can write this as

$$\frac{4}{3}\pi r^3 \approx A$$

thus

$$r = \frac{3}{4\pi} A^{1/3}$$

which can be written as $r = r_0\,A^{1/3}$ where r_0 is some constant.

(a)(iii) For neon-20 A = 20:

r = (1.2 x 10^{-15} m) x $20^{1/3}$ = 3.2 x 10^{-15} m,

so the diameter is

2 x (3.25 x 10^{-15} m) = 6.5 x 10^{-15} m.

(b) Electrons have a well-defined de Broglie wavelength, hence a well-defined frequency that can be represented by a rotating phasor. The electron waves explore all possible paths to the detector. The phasor for each path will arrive with a different angle (phase differences). Superposition of the phasors will give different amplitudes resulting in maxima and minima. The behaviour is similar to the diffraction of light around a small obstacle.

(c)(i) θ_{min} from the graph = 5°.
Diameter of neon-20 = 6.5×10^{-15} m (see **(a)(iii)**) thus

$\lambda = 1.2 \times (6.5 \times 10^{-15}\text{ m}) \times \sin 5° = 6.8 \times 10^{-16}$ m.

(c)(ii) $\lambda = h / p$ so

$p = h / \lambda = (6.63 \times 10^{-34}\text{ J s}) / (6.8 \times 10^{-16}\text{ m}) = 9.8 \times 10^{-19}$ N s.

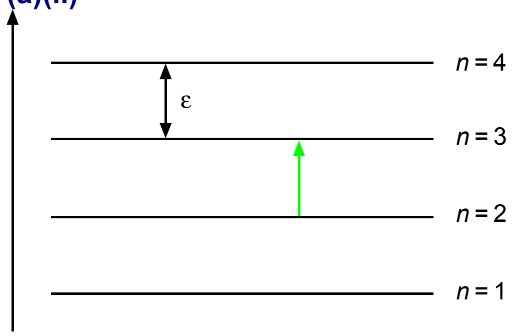
(d) The argon-40 graph has two differences from the neon-20 graph: (a) the diffracted signal is larger and (b) the minimum is shifted to a smaller angle.
Argon-40 will make a larger diameter target than the neon-20: $\sin \theta \sim \lambda / b$, so as b increases $\sin \theta$, and hence θ, gets smaller.
The argon nucleus has more protons and hence a larger charge than the neon, so more electrons in the beam will be affected to give a stronger signal.

Question 16

(a)(i) $c = f\lambda$ so $f = c / \lambda$. From the graph λ = 73 nm = 73×10^{-9} m:

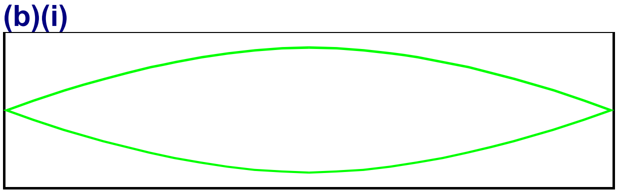
$f = (3 \times 10^{8}\text{ m s}^{-1}) / (73 \times 10^{-9}\text{ m}) = 4.1 \times 10^{12}$ Hz.

(a)(ii)



(a)(iii) $\varepsilon = hf = (6.6 \times 10^{-34}\text{ J s}) \times (4.1 \times 10^{12}\text{ Hz}) = 2.7 \times 10^{-21}$ J.

(b)(i)



(b)(ii) $\lambda = h / p$ and $E = p^2 / 2m$ thus

$p = \sqrt{2mE}$

so

$$\lambda = \frac{h}{\sqrt{2mE}} = \sqrt{h^2 / 2mE}.$$

(b)(iii)

$$\lambda = (6.6 \times 10^{-34}\ \text{J s})^2 / \sqrt{2 \times (5.1 \times 10^{-26}\ \text{kg}) \times (1.35 \times 10^{-21}\ \text{J})}$$
$$= 5.6 \times 10^{-11}\ \text{m}.$$

(c)(i) When n = 1, the successive nodes at the ends of the box correspond to half a wavelength. So the length of the box = (5.6 x 10^{-11} m) / 2 = 2.8 x 10^{-11} m.

(c)(ii) For n = 3:

$$E = (1.35 \times 10^{-21}\ \text{J}) + 2\varepsilon$$
$$= 1.35 \times 10^{-21}\ \text{J} + [2 \times (2.7 \times 10^{-21}\ \text{J})]$$
$$= 6.75 \times 10^{-21}\ \text{J}$$

and

$$\lambda = \sqrt{h^2 / 2mE} = 2.5 \times 10^{-11}\ \text{m}.$$

For n = 3, box length = 1.5 λ = 3.8 x 10^{-11} m, which is larger than for the ground state.

Question 17

Equating baryon numbers 239 +1 = 100 + 134 + n.
Thus n = 240 – 234 = 6 (minus the original inducing neutron, = 5 neutrons emitted by the plutonium-239)

Question 18

(a) $T_{1/2}\,\lambda$ = ln 2 thus

λ = ln 2 / (9.4 x 10^3 s) = 7.37 x 10^{-5} s^{-1} ~ 7 x 10^{-5} s^{-1}.

(b) Given

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$\lambda \approx \frac{\Delta N}{N\,\Delta t}.$$

ΔN and N have no units (they are just numbers) thus λ has the same units as $1 / \Delta t = s^{-1}$.

(c) Using the radioactive exponential decay equation (see **(b)**):

3×10^3 Bq = $(7.37 \times 10^{-5}\ s^{-1})\ N$

giving $N = 4.1 \times 10^7$ atoms.

Question 19

Risk per X-ray = probability per unit dose x dose equivalent
= 3% Sv^{-1} x (2×10^{-4} Sv)
= 6×10^{-4} % per year.

Over 25 years the risk = (6×10^{-4} % per year) x 25 years = 1.5×10^{-2} %.

Question 20

$E = m c^2$

$m = E / c^2$

E = 1.2 MeV = $(1.2 \times 10^6\ \text{eV}) \times (1.6 \times 10^{-19}\ \text{J eV}^{-1}) = 1.92 \times 10^{-13}$ J.

Thus

$$m = \frac{1.92 \times 10^{-13}\ \text{J}}{(3 \times 10^8\ \text{m s}^{-1})^2} = 2.1 \times 10^{-30}\ \text{kg}.$$

Note: this is of the same order of magnitude as the mass of an electron.

Question 21

(a)(i) Initial mass = 2 x 2.0141 u = 4.0282 u.

Final mass = 3.0160 u + 1.0087 u = 4.0247 u.

Difference = 4.0282 u – 4.0247 u = 0.0035 u.

(a)(ii) Convert u to kg:

0.0035 u x (1.66×10^{-27} kg u^{-1}) = 5.81×10^{-30} kg.

$E = m c^2 = (5.81 \times 10^{-30}\ \text{kg}) \times (3 \times 10^8\ \text{m s}^{-1})^2 = 5.2 \times 10^{-13}$ J.

(b)(i) We need to represent the process proton → neutron + positron + neutrino:

$${}^1_1\text{p} \rightarrow {}^1_0\text{n} + {}^0_1\text{e} + {}^0_0\nu.$$

Notice that the electric charge numbers and mass numbers must balance: the neutrino is uncharged and massless.

(b)(ii) 1.0073 u – 1.0087 u – 0.00055 u = –0.00195 u.

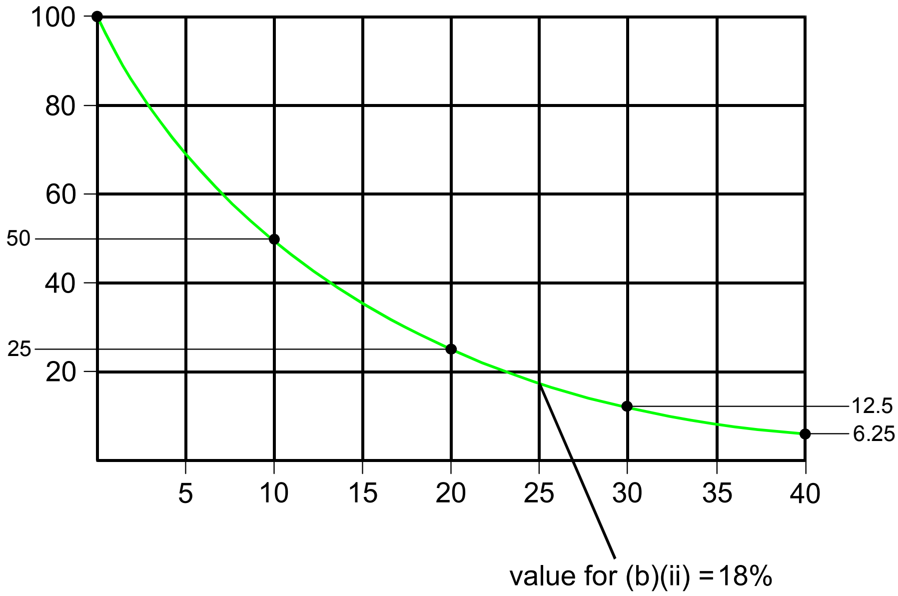
(b)(iii) The mass of the products is greater than the mass of the proton, so the process would require an energy input.

Question 22

(a) Activity $\Delta N / \Delta t = -\lambda N$

$T_{1/2}\,\lambda = \ln 2$, thus a longer half-life $T_{1/2}$ implies a smaller decay constant λ. So for λN to be the same (= the activity), the longest half-life requires the largest number of active particles N.

(b)(i)



(b)(ii) 25 mm gives 18% transmission:

$$\frac{18}{100}\times(4\times10^4) = 7.2\times10^3 \text{ Bq.}$$

(c)(i) Radiation is emitted in all directions, so at most only half will be towards the student's body.

(c)(ii) Exposure is for 1 hour = 3600 s:

dose = absorbed energy = ½ [(4 x 10^4 Bq) x 3600 s x (8.8 x 10^{-14} J)] = 6.3 x 10^{-6} J.

(c)(iii) Beta radiation will be absorbed only fairly close to the source, so will not be absorbed evenly by the whole body. Thus the dose equivalent to the body tissue around the source will be much higher than 0.1 μSv. If only 1 kg of body tissue absorbed the radiation, then the dose equivalent for that kg is (0.1 x 10^{-6} Sv) x 65 ~ 6.5 μSv, which is still much smaller than that due to background radiation, so the risk is still small.

Question 23

(a)(i) The rotating coil cuts line of magnetic flux, so the flux linked is changing. Changing magnetic flux induces an emf in the windings of the coil.

(a)(ii) Note that the car is **not** being slowed down by ordinary brakes. It is using the back emf. The car is slowing down, so the emf cannot be constant (so the answer is not A). The rate of rotation will decrease, thus the rate of cutting magnetic flux lines will also decrease, so B and C which show initial increases are not relevant. This leaves D as the correct answer.

(b) Either relatively large total mass (due to batteries etc) so since $a = F / m$, the acceleration is poor. Also, maximum power from batteries is less than available from burning petrol in a petrol engine.

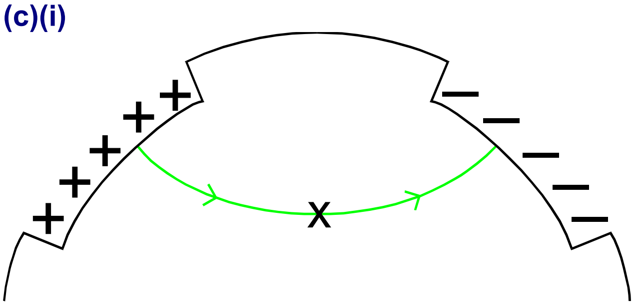
Question 24

(a)(i) The electrical resistance of the larger wires will be less, because although they are twice as long, their cross-sectional area is four times larger. Thus for a given p.d., the electric current will be greater. A larger current gives a larger magnetic flux.

(a)(ii) The magnetic circuit of the larger device is twice as long but has four times the cross-sectional area. Thus a given number of current turns produces a larger flux density.

(b) Centripetal force ~ $\omega^2 r$. For a given rotational speed ω, the force increases as r gets larger. This force is supplied by the tensile stress in the rotor arm, so in larger rotors the breaking stress may be exceeded.

(c)(i)



(c)(ii) The electric field exerts a force on the electric charge (in this case towards the + and away from the –), thus causing the rotor to rotate (anticlockwise).

Question 25

(a) To remove photons that have not come from the sodium iodide crystal.

(b)(i)

$$E = -\frac{dV}{dx},$$

i.e. E is the slope of the V versus distance graph which is constant, so E is constant.

(b)(ii) Slope of the graph = 80 V / (5 x 10^{-3} m) = 16 000 V m^{-1}.

(b)(iii) Force = $e\,E$ = (1.6 x 10^{-19} C) x (16 x 10^3 N C^{-1}) = 2.56 x 10^{-15} N ~ 2.6 x 10^{-15} N.
(NB: The value of *e* is on the information sheet used in all written exams.)

(b)(iv) $F = m\,a$, thus:

$$a = \frac{F}{m} = \frac{2.56\times10^{-15}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}$$
$$= 2.8\times10^{15}\ \text{m s}^{-2}.$$

This is enormously greater than *g* (9.8 m s^{-2}).
(NB: the value of *m* is on the information sheet used in all written exams.)

Question 26

(a) Fact 1: curves the opposite way, thus the positron must be travelling in the opposite direction from D to C.
Fact 2: the track is less curved, thus the positron is travelling faster.

(b) The process must obey conservation of electric charge. The gamma photon has zero charge, so the pair of particles produced must have zero net charge, i.e. opposite and equal charges.

(c) The gamma photon, being uncharged, does not ionise gas molecules very readily.

(d) Because they are both electrically charged and readily ionise the molecules (thus leaving tracks) they are losing energy and thus are slowing down.

(e) The positron meets an electron and annihilates into a pair of uncharged gamma photons which leave no tracks.

Question 27

(a) Solve these type of problems by applying the conservation laws: e.g. the decay must balance electric charge, baryon number, lepton number etc.
Baryon number does balance (14 = 14), so X is not a baryon (i.e. a neutron or proton).
Electric charge will balance if X has a charge of –1 (6 = 7 – 1).
Lepton number will balance if X has a lepton number of +1 (0 = 1 – 1, the anti-neutrino = –1).
Hence X is a lepton, with one unit of negative electric charge, and is thus a beta particle (electron).

(b) $T_{1/2}\,\lambda$ = ln 2. Hence:

$$T_{1/2} = \frac{\ln 2}{3.8 \times 10^{-12}\ \text{s}^{-1}}$$
$$= 1.8 \times 10^{11}\ \text{s}$$
$$= \frac{1.8 \times 10^{11}\ \text{s}}{3.2 \times 10^{7}\ \text{s year}^{-1}}$$
$$= 5.70 \times 10^{3}\ \text{years} \approx 6000\ \text{years.}$$

(c)(i) Mass of one carbon atom = 14 x (1.7 x 10^{-27}) kg. Thus the number of carbon atoms in 1.3 x 10^{-11} kg is

$$\frac{1.3 \times 10^{-11}\ \text{kg}}{14 \times (1.7 \times 10^{-27})\ \text{kg atom}^{-1}} = 5.46 \times 10^{14}\ \text{atoms}$$
$$\approx 5 \times 10^{14}\ \text{atoms.}$$

(c)(ii) The basic radioactive exponential decay equation is $\Delta N / \Delta t = -\lambda N$.
$\Delta N / \Delta t$ is the activity = (3.8 x 10^{-12} s^{-1}) x (5.5 x 10^{14} atoms) = 2.09 x 10^{3} Bq ~ 2 kBq.

(d)(i) 5000 years is almost one half-life, so the activity will have dropped by about ½, to about 1 kBq.

(d)(ii) The mass required = 10 / 1000 = 1 / 100 which corresponds to 0.65 kg which if removed will substantially damage the specimen.

(e)(i) Energy absorbed per second = activity x energy per decay
= 2000 Bq x (2.5 x 10^{-14} J $decay^{-1}$)
= 5.0 x 10^{-11} J s^{-1}.

(e)(ii) 1 Gy is the absorbed dose per kg. Thus absorbed dose is:

$$\frac{5.0 \times 10^{-11}\ \text{J s}^{-1}}{65\ \text{kg}} = 7.69 \times 10^{-13}\ \text{Gy s}^{-1}$$
$$= (7.69 \times 10^{-13}\ \text{Gy s}^{-1}) \times (3.2 \times 10^{7}\ \text{s year}^{-1})$$
$$= 2.5 \times 10^{-5}\ \text{Gy year}^{-1}.$$

(e)(iii) There is much more potassium-40 in the body than carbon-14.
May be potassium-40 is more active than carbon-14.
May be radiation from potassium-40 is more energetic than that from carbon-14.