N12/4/PHYSI/HP3/ENG/TZ0/XX/M

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MARKSCHEME

November 2012

PHYSICS

Higher Level

Paper 3

22 pages

Subject Details: Physics HL Paper 3 Markscheme

Mark Allocation

Candidates are required to answer questions from **TWO** of the Options **[2 ˜ 30 marks]**.
Maximum total = **[60 marks]**.

1. A markscheme often has more marking points than the total allows. This is intentional.

2. Each marking point has a separate line and the end is shown by means of a semicolon (;).

3. An alternative answer or wording is indicated in the markscheme by a slash (/). Either wording can be accepted.

4. Words in brackets ( ) in the markscheme are not necessary to gain the mark.

5. Words that are underlined are essential for the mark.

6. The order of marking points does not have to be as in the markscheme, unless stated otherwise.

7. If the candidate's answer has the same "meaning" or can be clearly interpreted as being of equivalent significance, detail and validity as that in the markscheme then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect).

8. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

9. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking indicate this by adding **ECF** (error carried forward) on the script.

10. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the markscheme.

Option E — Astrophysics

E1. (a) (i) the apparent magnitude/log scale of apparent brightness/measure of apparent brightness of a star at a distance of 10 pc / a (logarithmic) measure of the luminosity of a star; ***[1]***

(ii) temperature/colour; ***[1]***

(iii) star A has higher luminosity/brightness/mass at the same temperature/class / star A is near the red giant region;
(so it must be larger in radius) ***[1]***

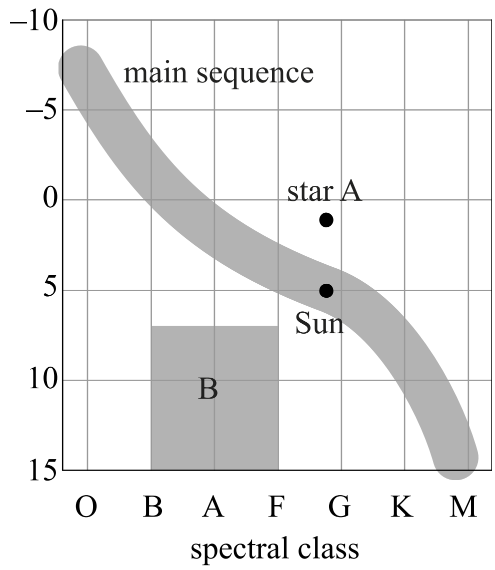
(b) (i) $\frac{L_A}{L_B} = \frac{\sigma 4\pi R_A^2 T_A^4}{\sigma 4\pi R_B^2 T_B^4}$;

$\frac{L_A}{L_B} = 0.60^4 \times 270^2$ ***or*** look for 3 or more sig fig *eg* 9.45×10^3;

$\left(\frac{L_A}{L_B} = 9.4 \times 10^3\right)$ ***[2]***

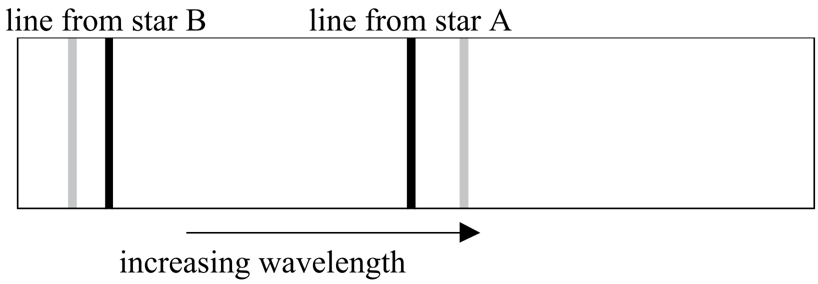
(ii)

absolute magnitude



anywhere in the grey box; ***[1]***

(c)



*Award **[1]** for each correct line.* ***[2]***
The shifted lines are light grey in the diagram above. Ignore magnitude of shift.
*Award **[0]** if more than two lines are drawn unless it is clear which lines are to be marked.*

E2. (a) (i) the star expands and contracts/pulsates / radius oscillates / *OWTTE*; ***[1]***

(ii) average absolute magnitude/$M = \left(-2.83\log_{10} 7.2 - 1.81\right) = -4.24$;
average apparent magnitude/$m = 4.0$;
$d = 10\times 10^{(m-M)/5} = 10\times 10^{(4.0+4.2)/5} = 436 \approx 440\,\text{pc}$; ***[3]***
Answer very sensitive to rounding. Allow 436 to 445 pc.
*Award **[3]** for a bald correct answer.*
*Allow ECF **[2 max]** for 164 pc obtained by assuming (7.2 – 1.81) is in brackets.*

(b) measure period and average apparent brightness/magnitude of the Cepheid to determine its distance;
measuring the apparent brightness of the star gives the luminosity (since distance is now known) from $L = 4\pi d^2 b$; ***[2]***

or

measure period of Cepheid to determine its (average) luminosity;
compare the apparent brightness of the star and Cepheid to find L using $L \propto b$;

E3. (a) (i) a universe whose density is equal to the critical density; ***[1]***

(ii) the mutual gravitational attraction would slow the expansion down; ***[1]***

(iii) the density of the universe needs to be determined;
this involves many uncertainties related to measurement of distances/volume;
this involves many uncertainties related to presence of dark matter; ***[2 max]***

(b) light from galaxies is observed to be red-shifted/to have a longer wavelength than that emitted;
indicating that the distance between galaxies is getting bigger/galaxies move away from each other/from us; ***[2]***
*Award **[1 max]** if galaxies are not mentioned.*

or

the presence of the cosmic microwave background radiation;
is evidence of cooling of the universe/increase in wavelength/red-shift due to expansion;

E4. (a) (i) L/luminosity $= 2.2^{3.5} L_{\odot}$;

$(L \approx 16 L_{\odot})$ ***[1]***

Some explanatory algebra required, not just $2.2^{3.5}$.

(ii) $\left(\text{since } T \propto \frac{M}{L}\right) \frac{T}{T_{\odot}} = \left[\frac{M_{\odot}}{M}\right]^{2.5}$ ***or*** $\frac{T}{T_{\odot}} = \left[\frac{M}{M_{\odot}}\right]^{-2.5}$;

$\frac{T}{T_{\odot}} = \left(\frac{1}{2.2^{2.5}} =\right) \frac{1}{7.2}$;

(the lifetime will be approximately 7 times less than that of the Sun) ***[2]***

or

$\frac{T}{T_{\odot}} = \frac{M}{L} \times \frac{L_{\odot}}{M_{\odot}}$;

$= \frac{2.2}{16} = 0.14$;

(the lifetime will be approximately 7 times less than that of the Sun)

Be careful to check that the working is valid for the value obtained.

(b) (i) *main sequence* → red giants → planetary nebula → *white dwarf* ***[2]***

(ii) less than the Chandrasekhar limit / less than $1.4 M_{\odot}$; ***[1]***

E5. (a) $\frac{\Delta\lambda}{\lambda} = 0.204 = \frac{v}{c} \Rightarrow v = 6.12 \times 10^{4}\ \text{km s}^{-1}$;

so $H = \frac{v}{d} = \frac{6.12 \times 10^{4}}{820} = 74.6\ \text{km s}^{-1}\ \text{Mpc}^{-1}$; ***[2]***

*Award **[2]** for a bald correct answer.*
*Award **[1 max]** if power of ten error in first marking point is carried forward.*

(b) present value of expansion rate is used for estimate;
but in the past the expansion rate was greater; ***[2]***

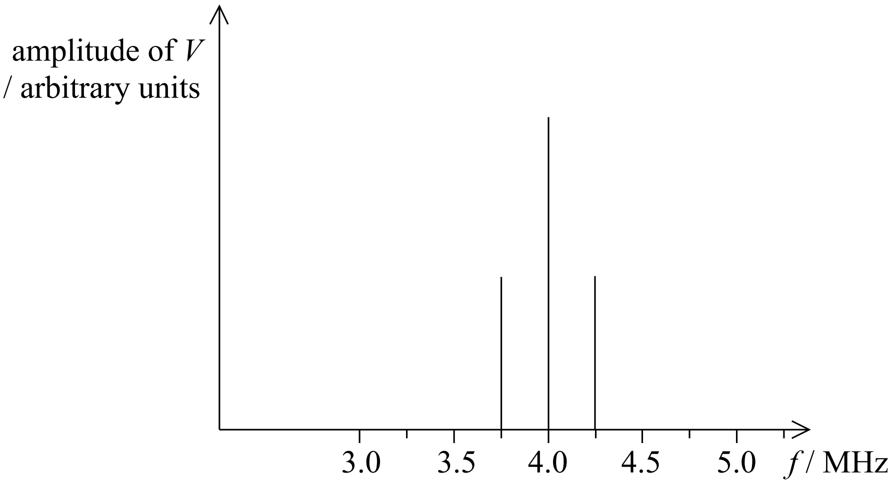
Option F — Communications

F1. (a) (i) (24 full waves in $6\,\mu s$ so) 4 MHz; *[1]*

(ii) (period is time from peak to peak of envelope *i.e.* $4\,\mu s$ so) 0.25 MHz; *[1]*

(iii) $\left(\frac{\max - \min}{2} = \frac{3.2 - 0.8}{2}\right) = 1.2\,V$; *[1]*

(b) three lines at the correct frequency;
sidebands shorter length; *[2]*



F2. (a) (i) *X*: analogue-to-digital converter;
Y: parallel-to-serial converter; *[2]*

(ii) the bits arrive at the serial-to-parallel converter <u>one after the other</u>/ <u>sequentially</u> (*OWTTE*) and are registered;
the bits are then <u>simultaneously</u> (*OWTTE*) fed in to the DAC; *[2]*

(b) need a larger sampling frequency;
in order to see variation of signal on a shorter time scale;
need a greater number of bits (in each digitized sample);
in order to make the vertical step size smaller / in order to reduce the quantization error; *[4]*

F3. (a) less noise/attenuation per unit length/crosstalk;
greater bandwidth/security (though encryption); ***[1 max]***

(b) attenuation/loss of energy depends on wavelength;
and is least for infrared wavelengths; ***[2]***

(c) (i) $10\log\frac{P_{\text{signal}}}{P_{\text{noise}}} = 25 \Rightarrow P_{\text{signal}} = 4.2\times10^{-6}\times10^{2.5}$;
(=1.3 mW) ***[1]***

(ii) $\text{loss in dB} = 10\log\frac{25}{1.3}$;
$\text{loss} = 12.8\text{ dB}$;
$L = \frac{12.8}{0.30} = 43\text{km}$; ***[3]***
*Award **[3]** for a bald correct answer.*

F4. (a) infinite input impedance/resistance;
infinite open loop gain;
zero output impedance; ***[2 max]***

(b) $G = 26 = 1 + \frac{R}{4}$;
$R = 100\text{k}\Omega$; ***[2]***
*Award **[2]** for a bald correct answer.*

(c) (i) $V_{\text{OUT}} = -7.8\text{V}$; *(minus sign required)* ***[1]***

(ii) $V_{\text{OUT}} = 9.0\text{V}$; ***[1]***

F5. (a) a larger cell size would require a larger power from base stations/mobile phones;
and this would imply greater health risks; ***[2]***

or

signal strength decreases with distance/is attenuated by buildings;
if cells are too large then signal strength will become too weak;

(b) (the cellular exchange allocates a) range of carrier frequencies within the same cell;
by allocating different time slots using time division multiplexing; ***[2]***

Option G — Electromagnetic waves

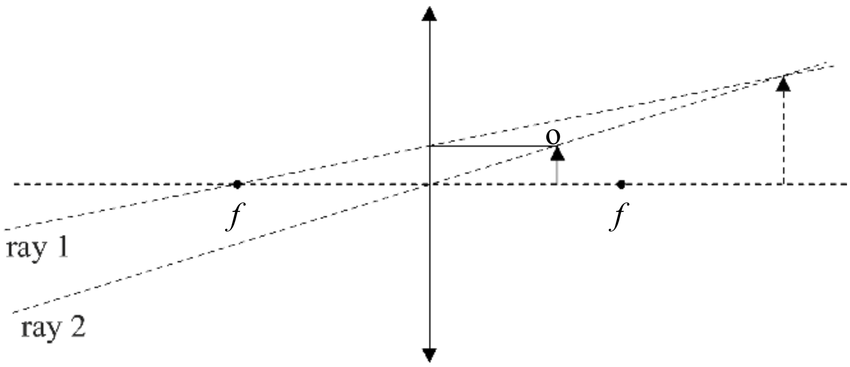
G1. (a) the light from the sources must be coherent / phase difference must be constant *(allow "in phase")* / the electric fields must have the same polarization; ***[1]***

(b) fringe spacing $= \frac{1.60\,\text{m} \times 410\,\text{nm}}{0.30\ \text{mm}}$;
2.2 mm; ***[2]***
*Award **[2 max]** for a response that makes use of* $n\lambda$ *in the double slit formula*
*Award ECF **[1 max]** if answer is for a value of n greater than 1.*
*Award **[2]** for a bald correct answer.*

(c) sharper fringes / *OWTTE*;
brighter;
same spacing; ***[3]***

G2. (a) the near point is the closest position of an object from the eye that can be clearly focused / objects placed closer than the near point cannot be focused clearly by the eye / *OWTTE*; ***[1]***

(b)



ray 1 correct;
ray 2 correct;
virtual rays converge/image shown; ***[3]***
Ignore arrows on any lines drawn.

(c) $M = \left(\frac{\theta_i}{\theta_o} = \right)(-)\frac{v}{u}$;

$= \frac{D}{\frac{fD}{f+D}} = \frac{D(f+D)}{fD}$;

$\left(M = 1 + \frac{D}{f}\right)$ ***[2]***

Check for correct manipulation.

(d) (i) $M = \left(1 + \frac{25}{6} =\right) 5.2$; ***[1]***

(ii) $\frac{1}{v} = \frac{1}{2.8} - \frac{1}{3.4}$;
$v = 16\,\text{cm}$; ***[2]***
*Award **[2]** for a bald correct answer.*
*Award **[1]** for ECF giving v = 1.5 cm.*

(iii) magnification of objective $= \left(\frac{16}{3.4} =\right) 4.7$;
overall magnification $= (5.2 \times 4.7 =) 24$; ***[2]***
*Award **[2]** for a bald correct answer.*
*Award **[2 max]** for ECF from (d)(i) and (d)(ii).*

G3. blue/short wavelength light is scattered most in the atmosphere;
at sunset, sunlight passes through a greater thickness of atmosphere;
so the Sun/sky/clouds appear redder due to removal of blue / *OWTTE*; ***[3]***

G4. (a) (i) electrons are accelerated through a (high) potential difference;

continuous:
after acceleration they strike a (metal) target;
rapid deceleration leads to continuous part of the spectrum/bremsstrahlung;

characteristic:
electrons strike target ejecting inner shell electrons;
transition of outer electron produces X-ray photon / *OWTTE*; ***[4 max]***

(ii) changing the temperature of the filament changes the number of electrons produced;
changing the number of electrons changes the number of photons/intensity of X-rays; ***[2]***

or

changing the accelerating pd changes the energy of electrons;
which changes the X-ray intensity/number of X-ray photons;

(b) (i) use of $\lambda = \frac{hc}{Ve}$;

$= \frac{6.6\times10^{-34}\times3\times10^{8}}{2.5\times10^{4}\times1.6\times10^{-19}} = 4.95\times10^{-11}\text{m}$;

$(= 5.0\times10^{-11}\text{ m})$ ***[2]***

(ii) $d = \frac{5\times10^{-11}}{2\times\sin19^{\circ}}$;

$= 7.7\times10^{-11}\text{m}$; ***[2]***

*Award **[2]** for a bald correct answer.*

*Award **[1 max]** if factor of 2 is not used giving 1.5×10^{-10} m.*

Option H — Relativity

H1. (a) a point in spacetime / something happening at a particular time and a particular point in space; ***[1]***

(b) (i) $t = \frac{6.0}{3.0 \times 10^8} = 2.0 \times 10^{-8}\,\text{s}$; ***[1]***

(ii) for either formula to be used one of the time intervals must be a proper time interval;
the two events occur at different points in space and so neither observer measures a proper time interval;
the proper time interval is that of the photons; ***[2 max]***

(c) (i) $\gamma = \frac{1}{\sqrt{1-0.80^2}} = \frac{5}{3} = 1.67$;
$l = \frac{L}{\gamma} = \frac{6.0}{1.67} = 3.6\,\text{m}$; ***[2]***
*Award **[2]** for a bald correct answer.*

(ii) c; ***[1]***

(iii) vT ***or*** $0.80\,cT$; ***[1]***

(iv) $cT = 0.80\,cT + 3.6$;
$T = \frac{3.6}{0.20 \times 3.0 \times 10^8} = 6.0 \times 10^{-8}\,\text{s}$; ***[2]***
*Award **[2]** for a bald correct answer.*

(d) accurate atomic clocks were carried aboard airplanes for some time;
upon return they were compared with similar clocks in the lab;
the clocks on the ground and in the airplane(s) recorded different/lesser/greater times in accordance with special relativity/general relativity; ***[3]***

H2. (a) (i) the mass of an object in its rest frame / the mass as measured by an observer at rest with respect to the body; ***[1]***

(ii) a quantity that is the same for all observers/reference frames; ***[1]***

(b) (i) speed of X relative to Y is $\left(\frac{0.60\,c-(-0.60\,c)}{1+0.60^2}\right)=0.882c$;

gamma factor at this speed is $\gamma=\frac{1}{\sqrt{1-0.882^2}}=2.12$;

momentum is then $p=\gamma mv=2.12\times380\times0.882\,c=710\text{ MeV}\,c^{-1}$; ***[3]***

*Award **[3]** for a bald correct answer between 700 MeV c^{-1} and 713 MeV c^{-1} due to rounding.*

(ii) $Mc^2=2\times\gamma mc^2=2\times\frac{5}{4}\times380$;

$\Rightarrow M=950\text{ MeV c}^{-2}$; ***[2]***

*Award **[2]** for a bald correct answer.*

H3. (a) inertial and gravitational effects are indistinguishable / a freely falling frame in a gravitational field is equivalent to an inertial frame far from all masses / an accelerating frame is equivalent to a frame at rest in a gravitational field; ***[1]***

(b) (i) *The question does not specifically state the location of the tower so allow any of the explanations below.*

(the principle of equivalence predicts) photon energy decreases as it moves against a g field;
this energy is given by $E = hf$;
hence as E decreases, f must also decrease; ***[3]***

or

the tower is equivalent to a frame accelerating upwards;
the top of the tower is moving away from the light emitted from the base;
and so by the Doppler effect/red-shift the frequency at the top will be less;

or

in freely falling tower the frequency at the top and bottom would be the same;
an outside observer sees the top moving towards the light emitted from the base and so (by the Doppler effect) expects a blue-shift;
for the frequency to be the same at the top the light moving upwards must suffer an equal red-shift;

(ii) 8.8×10^3 Hz / 8.9×10^3 Hz / 9.0×10^3 Hz; ***[1]***

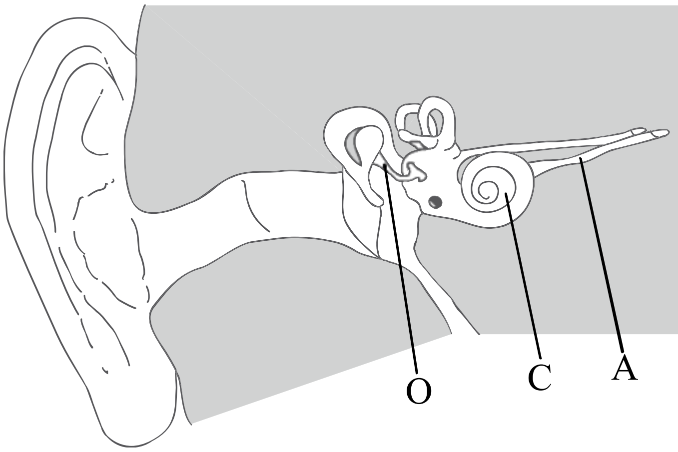
(iii) $\frac{\Delta f}{f}\left(=\frac{8.8\times10^3}{3.5\times10^{18}}\right)\approx10^{-15}$ / the shift is very small compared to the original frequency / the new frequency differs from the original in the 15th decimal place; ***[1]***

H4. (a) the distance from the black hole where the escape speed is the speed of light / the distance from the black hole inside which nothing can escape; ***[1]***

(b) light travels along – geodesics/paths of shortest length;
geodesics/light paths – follow the curvature of spacetime / *OWTTE*;
spacetime is more curved nearer/less curved further from a black hole; ***[3]***

Option I — Medical physics

I1. (a)



(i) C labelled correctly; ***[1]***

(ii) O labelled correctly; ***[1]***

(iii) A labelled correctly (either or both nerves); ***[1]***

(b) (i) $20(\pm 5) + \text{Hz} \rightarrow 18(\pm 3)$ kHz; ***[1]***

(ii) lower limit stays the same;
upper limit decreases; ***[2]***
*Award **[1 max]** for "the range decreases".*

(c) the increase in loudness is proportional to the fractional change in sound intensity / increase in loudness $\propto \dfrac{\text{intensity increase}}{\text{initial intensity}}$;
the loudness will increase by the same amount each time the intensity is doubled;
the loudness/intensity level is not proportional to intensity but increases with the log of intensity / states <u>and</u> explains the intensity level equation; ***[2 max]***

(d) $\left(10\log\left[\dfrac{10^{-6}}{10^{-12}}\right]\right) = 60\,\text{dB}$;

$\left(60 \times 2 = 120 = 10\log\left[\dfrac{I}{10^{-12}}\right] \Rightarrow\right) I = 1.0\,\text{W m}^{-2}$;

increase in intensity $= 10^6$; ***[3]***
Allow interpretation of "increase" as the difference between the two intensities for third marking point. Gives 1.0 W m^{-2} of course, but must be separately stated to award the mark.

I2. (a) the intensity of the beam I falls by a constant amount dI through each distance dx travelled such that;

$\frac{dI}{I} = -\mu dx$ where μ is the attenuation coefficient; ***[2]***

or

$I = I_0 e^{-\mu x}$ where I_0 is the intensity of the beam as it enters the medium;
I is the intensity after the beam has travelled a distance x in the medium and μ is the attenuation coefficient;

or

the probability per unit length;
that a photon will be absorbed;

(b) $I = \frac{I_0}{2} = I_0 e^{-\mu x_{\frac{1}{2}}}$ so $e^{-\mu x_{\frac{1}{2}}} = \frac{1}{2}$;

$\mu = \frac{\ln 2}{x_{\frac{1}{2}}}$; ***[2]***

(c) μ for 15 keV $= \left(\frac{\ln 2}{0.7} =\right) 1.0\,\text{mm}^{-1}$ and μ for 30 keV $= \left(\frac{\ln 2}{3.5} =\right) 0.20\,\text{mm}^{-1}$;

$\left(\frac{\text{intensity of 15(keV) X-rays}}{\text{intensity of 30(keV) X-rays}}\right) = \frac{I_0 e^{-1.0\times 6.0}}{I_0 e^{-0.2\times 6.0}}$;

$= 8.2\times 10^{-3}$; ***[3]***

Allow similar approach using half value thickness directly in the exponent, without intermediate calculation of μ, to find ratio.
Without the same rounding error this gives 8.6×10^{-3}.
*Award **[3]** for a bald correct answer between 8.0 and 8.6×10^{-3}.*

(d) the attenuation coefficient of the liver and of the surrounding tissue for the X-rays have approximately the same value;
so no contrast can be obtained between liver and surrounding tissue / liver cannot be distinguished from surrounding tissue; ***[2]***

I3. (a) biological half-life is the time it takes for half the original amount of a radioactive isotope to be removed from the body by biological processes / *OWTTE*;
the effective half-life is the time it takes for the original activity of a radioactive isotope to halve due to the biological half-life and natural radioactive decay / *OWTTE*; ***[2]***

(b) (i) $\frac{1}{T_E} = \frac{1}{T_B} + \frac{1}{T_P} = \frac{1}{21} + \frac{1}{8.0}$;
$T_E = 5.8$ (days); ***[2]***
*Award **[2]** for a bald correct answer.*

(ii) iodine-131 will be localized to the thyroid/will not be spread throughout the body;
the effective half-life of nearly 6 days means that iodine remains in the body for enough time to be effective/before losing too much of its activity;
an effective half life of 6 days means that activity will decrease to very low/safe levels after a few weeks;
beta particles have a limited range in tissue so will interact with the cancer cells rather than escape to the environment / *OWTTE*;
the gamma emissions mean that the activity of the isotope in the body can be monitored externally; ***[3 max]***

(c) $\frac{510}{96} = 5.3$ times more activity for water sample;
so by (inverse) proportion this is the volume ratio;
volume of blood $= 5300\ \text{cm}^3$ ***or*** 5.3 litres; ***[3]***
*Award **[3]** for a bald correct answer.*
*Award **[2 max]** for an answer of 189 cm^3.*
*There are many possible alternative approaches to this problem. If an incorrect answer is obtained, use your own judgement to award **[2 max]** for any correct working.*

Option J — Particle physics

J1. (a) photon / graviton / Z / Higgs; ***[1]***

(b) (i) K^0 has a strangeness of +1, its antiparticle has strangeness –1 and so are different;
the antiparticle is s, $\bar{d}$ and so is different; ***[1 max]***

(ii) strangeness is violated in this decay;
this can only happen with the weak interaction; ***[2]***

(iii) Z^0 / Z; ***[1]***

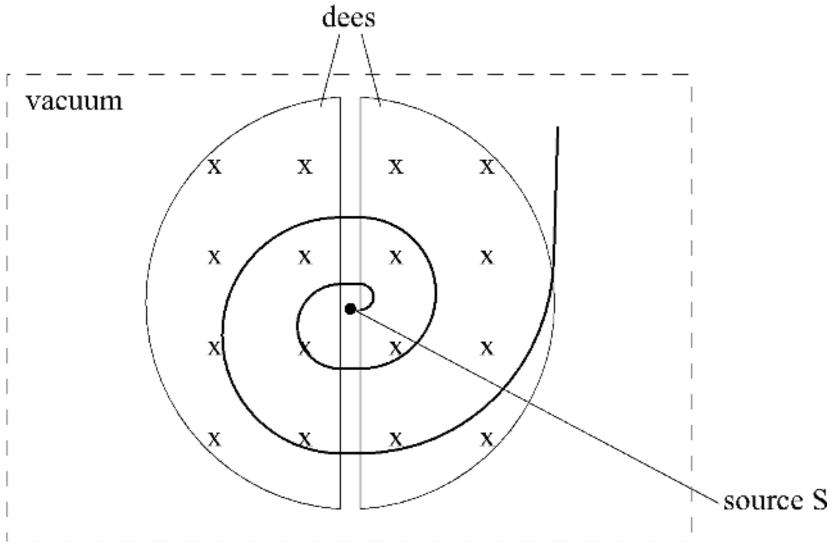
(iv) $R = \left(\frac{h}{4\pi mc} = \right)\frac{6.6\times10^{-34}}{4\times\pi\times1.6\times10^{-25}\times3.0\times10^{8}}$;
$R \approx 10^{-18}$ m; ***[2]***
*Award **[2]** for a bald correct answer.*

(c) (i) the K^0 consists of a quark and an antiquark of opposite colours/colour anticolour pair;
and so cancel out; ***[2]***

(ii) baryon number / quark number / energy; ***[1]***

J2. (a) (i) an alternating potential difference is applied to the "dees";
when the protons arrive at the gap of the dees they always face a negative potential;
when protons arrive at the gap they experience an acceleration/force;
because the frequency of the potential difference is the same as the frequency of revolution of the protons; ***[3 max]***

(ii) counterclockwise spiral as shown; ***[1]***



(b) $E_A = \sqrt{2mc^2E + 2(mc^2)^2} = \sqrt{2 \times 938 \times 8.0 + 2(938)^2}$;
$E_A = 1330$ MeV; ***[2]***
*Award **[2]** for a bald correct answer.*

(c) (i) to reconstruct the path of a particle / to detect the position of a particle; ***[1]***
Do not accept "to detect the particle".

(ii) the charged particle ionizes a gas/leaves ion trail;
the arrival times of the ions and electrons at the wires of the chamber can be measured very accurately;
using the known speed of electrons and ions in the gas the position of the charged particle can be precisely measured;
the information is digitized to reveal particle tracks; ***[3 max]***

J3. (a) the statement is true only for low energies;
at higher energies the strength of the strong interaction decreases; ***[2]***

(b) in deep inelastic scattering experiments the energy transferred to the constituents of hadrons is very large;
the scattering pattern is consistent with quarks inside hadrons behaving as free particles / the interaction between the constituents is very weak (asymptotic freedom); ***[2]***

(c) there are electrically neutral constituents inside hadrons / there are gluons within hadrons;
quarks come in (three) colours;
quarks are charged particles; ***[2 max]***

J4. (a) $\frac{3}{2}(kT) = 14\text{ TeV}$;

$$T = \frac{2 \times 14 \times 10^{12} \times 1.6 \times 10^{-19}}{3 \times 1.38 \times 10^{-23}} \approx 10^{17}\text{ K};$$ ***[2]***

*Award **[2]** for a 7 TeV response (5.4×10^{16} K).*
*Award **[2]** for a bald correct answer.*

(b) particles and antiparticles annihilated into photons but photons also materialized into particle antiparticle pairs;
as the universe cooled down photons could no longer produce particle antiparticle pairs and since there was a slight excess of particles the antiparticles disappeared; ***[2]***