Diploma Programme
Programme du diplôme
Programa del Diploma

# Markscheme

## May 2015

## Physics

## Higher Level

## Paper 3

19 pages

International Baccalaureate
Baccalauréat International
Bachillerato Internacional

**1.** Follow the markscheme provided, award only whole marks and mark only in **RED**.

**2.** Make sure that the question you are about to mark is highlighted in the mark panel on the right-hand side of the screen.

**3.** Where a mark is awarded, a tick/check (✓) **must** be placed in the text at the **precise point** where it becomes clear that the candidate deserves the mark. **One tick to be shown for each mark awarded.**

**4.** Sometimes, careful consideration is required to decide whether or not to award a mark. In these cases use RM™ Assessor annotations to support your decision. You are encouraged to write comments where it helps clarity, especially for re-marking purposes. Use a text box for these additional comments. It should be remembered that the script may be returned to the candidate.

**5.** Personal codes/notations are unacceptable.

**6.** Where an answer to a part question is worth no marks but the candidate has attempted the part question, use the "ZERO" annotation to award zero marks. Where a candidate has not attempted the part question, use the "SEEN" annotation to show you have looked at the question. RM™ Assessor will apply "NR" once you click complete.

**7.** If a candidate has attempted more than the required number of questions within a paper or section of a paper, mark all the answers. RM™ Assessor will only award the highest mark or marks in line with the rubric.

**8.** Ensure that you have viewed **every** page including any additional sheets. Please ensure that you stamp "SEEN" on any additional pages that are blank or where the candidate has crossed out his/her work.

**9.** There is no need to stamp an annotation when a candidate has not chosen an option. RM™ Assessor will apply "NR" once you click complete.

**10.** Mark positively. Give candidates credit for what they have achieved and for what they have got correct, rather than penalizing them for what they have got wrong. However, a mark should not be awarded where there is contradiction within an answer. Make a comment to this effect using a text box or the "CON" stamp.

**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**

**1.** (a) *A*: white dwarf;
*B*: main sequence / blue giant / blue supergiant;
*C*: red giant / red supergiant; **[3]**

(b) $\frac{L_B}{L_A} = \left(\frac{\sigma 4\pi R_B{}^2 T^4}{\sigma 4\pi R_A{}^2 T^4} = \right) 10^6$;

$\frac{R_B}{R_A} = 10^3$; **[2]**

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

(c) (i) *apparent brightness*: (total) power received per unit area/per m²; *(accept luminosity for power)*
*luminosity*: (total) power radiated; **[2]**
*Accept energy per second instead of power.*

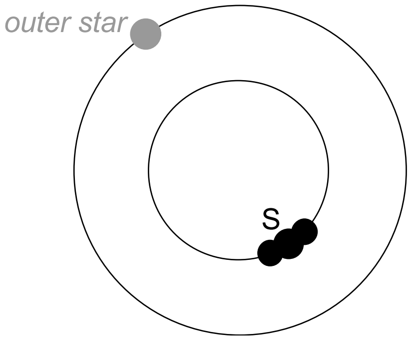
(ii) $d = \sqrt{\frac{L}{4\pi b}} \left(= \sqrt{\frac{10^4 \times 3.9 \times 10^{26}}{4\pi \times 3.8 \times 10^{-10}}}\right)$; *(mark is for rearrangement)*

$d = 2.9 \times 10^{19}$ (m); **[2]**

*Award **[1]** for $2.9 \times 10^{17}$ (misses factor of 10 000).*
*Award **[2]** for a bald correct answer.*

(d) same shape as curve in graph and displaced to right;
peak at $10 \pm 2 \times 10^{-7}$ m with intensity $\leq 1$; **[2]**

**2.** (a)

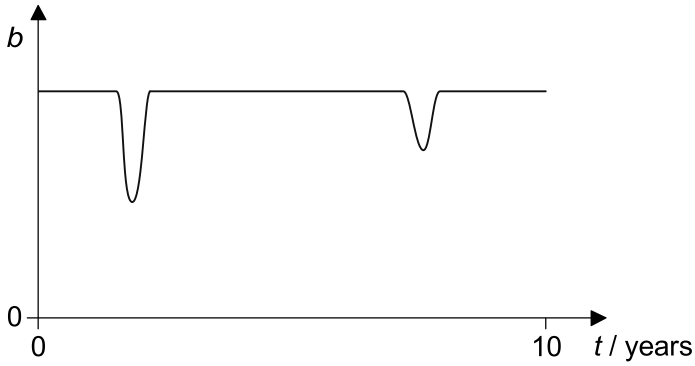



diametrically opposite on inner circle; } *(judge by eye – smaller dots show the range allowed)* **[1]**

*Do not accept multiple positions for S.*
*Ensure S is placed on the inner circle – it is easy to make a mistake.*

(b) the Earth/observer must be on the plane of the orbit;
alignment of stars is such that they can block the light from the other star as seen by the observer / *OWTTE*; **[1 max]**

(c)




exactly 2 minima in 10 years;
minima of different intensity and width of minima ≤ separation; **[2]**
*Award **[0]** for a single minimum.*
*Accept minima of any shape.*

**3.** (a) (distant) galaxies are all moving away from each other/Earth;
the distance between galaxies is increasing;
the volume/diameter/radius/scale factor of the universe is increasing;
space itself is stretching with time; **[1 max]**
*Do not accept answers such as "everything is moving away from everything else" as this is clearly not true.*

(b) (i) cosmic microwave background/CMB/CBR;
helium/hydrogen ratio/abundance;
darkness of night sky (Olbers' paradox); **[1 max]**
*Do not accept answers that refer to Hubble's law/red-shift of galaxies.*

(ii) CMB was a prediction of the Big Bang model;
radiation present in the early universe was at a high temperature/short wavelength;
as the universe expanded it cooled/wavelength increased;
so the radiation present today is in the microwave region / has temperature of 2.7 K; **[3 max]**

***or***

the early universe contained high energy neutrons/protons;
as the universe expanded and cooled (to $10^9$ K) nucleosynthesis could start, producing helium;
as the temperature dropped further, nucleosynthesis stopped leaving an excess of protons/hydrogen;
the current abundance of hydrogen and helium is consistent with the predictions of the Big Bang/expansion;

***or***

Olbers' paradox asks "why is the night sky dark?";
this cannot be explained if universe is infinite and static / *OWTTE*;
in an expanding universe some light is red-shifted out of visible range;
in a Big Bang universe some light from distant galaxies has not reached us yet;

**4.** (a) $\frac{L}{L_\odot} = 2^n$ with $n$ between 3 and 4;
so $8L_\odot < L < 16L_\odot$; **[2]**
*Award **[2]** for a bald correct answer.*

(b) (i) the core/remnant mass must be less than the Chandrasekhar limit/1.4 solar masses; *(must see core or remnant or similar term)* **[1]**

(ii) residual/thermal/internal energy of the star / *OWTTE*; **[1]**
*Do not allow fusion.*

(iii) C / O / Ne / Mg; *(accept no others)* **[1]**

(c) gravitational attraction/pressure is balanced by;
electron (degeneracy) pressure/repulsion / pressure/force due to Pauli exclusion principle; **[2]**
*Award the first marking point independently of the second.*

**5.** (a) combining $\frac{\Delta\lambda}{\lambda}=\frac{v}{c}$ and $v=H_0 d$ ; **[1]**

*Answer given, check working.*

(b) $d=\frac{c\Delta\lambda}{\lambda H_0}=\left(\frac{3\times10^5\times35}{620\times68}\right)$; *(mark is for rearrangement)*

$d=250\,(\text{Mpc})$ ***or*** $7.7\times10^{24}\,(\text{m})$ ; **[2]**

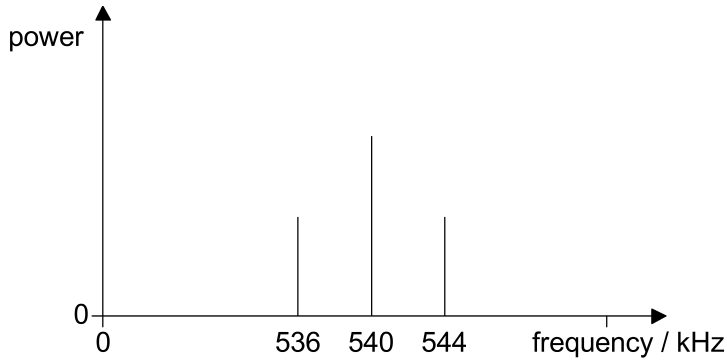
*Allow only first marking point if incorrect value for $\lambda$ is used.*
*Award **[2]** for a bald correct answer*.

**Option F — Communications**

**6.** (a) to transmit information/data;
the amplitude of a carrier wave is modified by signal waveform/displacement/amplitude / *OWTTE*; **[2]**

(b) (i) $(2 \times 4.0\,\text{kHz} =)\, 8.0\,(\text{kHz})$; **[1]**

(ii) line labelled 540;
side bands labelled with correct frequencies (536 and 544) and heights smaller than carrier height; *(allow ECF from (b)(i))* **[2]**




(c) *X*: RF amplifier;
*Y*: AF amplifier; **[2]**

**7.** (a) (i) $32 \times 44.1 \times 10^{3} = 1.41 \times 10^{6}\,(\text{bits s}^{-1})$; **[1]**

(ii) $\frac{1}{44.1}\,\text{kHz}$;
$2.27 \times 10^{-5}$ (s) ***or*** 23 (μs); **[2]**
*Do not accept bit time (710 ns).*
*Award **[2]** for a bald correct answer.*

(b) increase the sampling frequency;
less distortion / greater frequency range / better reproduction of original signal; **[2]**

***or***

increase number of bits per sample / increase bit rate/depth;
less noise / greater dynamic range / smaller changes in loudness/amplitude reproduced / better reproduction of original signal;
*Do not accept "to improve quality" as this repeats the question.*

(c) a method to transmit multiple signals along the same channel;
by placing samples of one signal in between samples of another signal;

*Award **[2]** for diagram showing*:
voltage versus time axes;
equally spaced samples of one signal and equally spaced samples of another signal in between; **[2 max]**

**8.** (a) for a ray attempting to move from a high to a low refractive index medium;
the phenomena in which the angle of incidence is greater than the critical angle;
(critical angle is) the angle of incidence for which the angle of refraction is $90^\circ$ / *OWTTE*;
leading to a reflected but not to a refracted ray; **[3 max]**
*Award **[3 max]** for a clearly drawn annotated diagram.*

(b) $\frac{\sin\theta_c}{\sin 90^\circ} = \left(\frac{\sin\theta_c}{1} = \right)\frac{1.50}{1.62}$;
$\theta_c = 67.8^\circ$; **[2]**
*Award **[2]** for a bald correct answer.*

(c) pulse width/duration increases / pulse amplitude decreases / colour separation; **[1]**

**9.** (a) very high (infinite) input resistance/impedance / zero input current;
very low (zero) output resistance/impedance;
very high (infinite) gain in the output voltage;
very high (infinite) bandwidth;
very low (zero) noise;
the output signal is proportional to the difference between the two input signals (assuming no saturation); **[2 max]**

(b) $V_- = V_+ = 0$;
$V_{IN} = I_1 \times R_1$ and $V_{OUT} = -I_2 \times R_2$; *(allow negative sign in either IR term)*
$I_1 = I_2$;
so $\frac{V_{IN}}{R_1} = -\frac{V_{OUT}}{R_2}$;
$\left(\text{therefore the gain is } \frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}\right)$ **[3 max]**
*Award **[3 max]** for very concise proof:* $I = \frac{V_{IN}}{R_1} = -\frac{V_{OUT}}{R_2}$.

(c) (i) $G = -12$;
$V_{OUT} = -8.4$ (V); **[2]**
*Allow ECF for use of $G = +12$.*

(ii) $V_{OUT} = -15$ (V); **[1]**
*Allow ECF for use of $G = +12$ in (c)(i).*

(iii) the input saturation limit is $\left(\frac{15}{12} = \right)1.25$ (V);
1.7 V is greater (so output is –15 V); **[2]**

***or***

$-12 \times 1.7\text{ V} < -15\text{ V}$;
so saturates / cannot “exceed” supply voltage;
*Allow ECF for use of $G = +12$ in (c)(i).*

**Option G — Electromagnetic waves**

**10.** (a) transverse waves / *OWTTE*;
consisting of an electric and a magnetic field at right angles to one another;
waves that can propagate in vacuum;
waves whose speed in vacuum is the speed of light/c; **[3 max]**

(b) *absorption*:
wave/photons transfer energy to atoms/molecules / cause excitation/ionization of atoms/molecules;

*scattering*:
change of direction of wave/photons as a result of interactions with particles; **[2]**
*Accept answers which combine the two processes. For example reference to scattering where optical excitation of atoms or molecules (absorption) is immediately followed by emission in all directions.*

(c) used in the storage and retrieval of data on CDs/DVDs/Blu-ray disks;
used in surveying/welding/machining metals/drilling holes in metals;
used in medical applications such as microsurgery (*eg*: eye-surgery);
used in guiding "smart" weapons to their target; **[1 max]**
*Accept any other reasonable use.*

**11.** (a) (i) identifying focal length from diagram ***or*** $f = 5.0\,\text{cm}$;
$\left(P = \frac{1}{f} = \frac{1}{5.0}\right) = 0.20\,(\text{cm}^{-1})$ ***or*** 20 (D) ***or*** $20\,(\text{m}^{-1})$; **[2]**
*Award **[2]** for a bald correct answer.*

(ii) first ray from tip of object correctly refracted by lens;
a second ray from tip of object correctly refracted;
correct extrapolation back to tip of image; **[3]**
*Accept rays without arrows and solid construction lines back to the image.*

(iii) image is virtual;
image cannot be formed on a screen / rays do not cross; **[2]**

(b) (i) $\theta_0 = \left(\frac{82}{4 \times 10^3} =\right) 2.05 \times 10^{-2}\,(\text{rad})$;
$M = \left(\frac{0.1}{2.05 \times 10^{-2}} =\right) 4.9$; **[2]**
*Allow ECF in second marking point for using incorrect angle.*
*Award **[2]** for a bald correct answer.*

(ii) $(f_o = 4.9 \times 15) = 74\,(\text{cm})$ ***or*** $73\,(\text{cm})$; *(allow ECF from (b)(i))* **[1]**
*Allow 75 (cm) due to rounding.*

**12.** (a) *reference to*:
diffraction at slits / slits are coherent sources;
path/phase difference;
constructive and destructive interference; **[2 max]**
*Do not reward just "interference" as this is mentioned in the question.*

(b) for single fringe: $s = \frac{650 \times 10^{-9} \times 1.8}{2.2 \times 10^{-3}} (= 5.3 \times 10^{-4}\ (\text{m}))$; *(also award this mark if the factor of 3 is seen in the numerator)*

distance $MP = (5.3 \times 10^{-4} \times 3 =) 1.6 \times 10^{-3}\ (\text{m})$; **[2]**
*Allow ECF from first marking point.*
*Award **[2]** for a bald correct answer.*

**13.** (a) (i) continuous spectrum / bremsstrahlung radiation;
characteristic/discrete spectrum;
$\lambda_{\text{min}}$ /minimum wavelength; **[3]**
*Award marking points for correct labelling of the graph.*

(ii) same shape but higher curve with spikes at the same wavelengths;
decreased $\lambda_{\text{min}}$; **[2]**

(b) $E = (4 \times 10^{4} \times 1.6 \times 10^{-19}) = 6.4 \times 10^{-15}\ (\text{J})$;

$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{6.4 \times 10^{-15}}$;

$(3.1 \times 10^{-11}\ \text{m})$ **[2]**

*Accept these steps as a single equation for **[2]**.*

***or***

$f_{\text{max}} = \left( \frac{1.6 \times 10^{-19} \times 40 \times 10^{3}}{6.63 \times 10^{-34}} = \right) 9.7 \times 10^{18}\ (\text{Hz})$;

$\lambda_{\text{min}} = \left( \frac{c}{f_{\text{max}}} = \right) \frac{3 \times 10^{8}}{9.7 \times 10^{18}}$;

$(3.1 \times 10^{-11}\ \text{m})$

*Answer given, award marks for correct working or >2 significant digits in final answer.*

(c) $\sin\theta = \frac{n\lambda}{2d}$; *(mark is for rearrangement, must include the 2)*

obtains angles 0.18 rad ***or*** $10^{\circ}$ and 0.55 rad ***or*** $31^{\circ}$;

difference 0.37 rad ***or*** $21^{\circ}$ ***or*** $22^{\circ}$; *(allow ECF from second marking point)* **[3]**
*If factor of 2 is missed only the last marking point can be awarded (ECF).*
*Award **[3]** for a bald correct answer.*

**Option H — Relativity**

**14.** (a) (i) $\left(\frac{12\,\text{ly}}{0.60c}=\right)20\,(\text{yr})$ ***or*** $6.3\times10^{8}\,(\text{s})$; **[1]**

(ii) $\gamma=\left(\frac{1}{\sqrt{1-0.60^{2}}}=\right)1.25$;

$\Delta t_{0}=\left(\frac{\Delta t}{\gamma}=\frac{20}{1.25}=\right)16\,(\text{yr})$ ***or*** $5.0\times10^{8}\,(\text{s})$; *(allow ECF from (a)(i))* **[2]**

*This question is worth **[2]**, but it is easy to accidently award **[1]**.*

(b) (i) the length of a body in the rest frame of the body; **[1]**

*Do not accept "event" instead of "object/body".*
*Do not accept "in the same frame" unless rest (OWTTE) is mentioned.*

(ii) $l=\frac{310}{1.25}$; *(allow ECF from (a)(ii))*

$=250\,(\text{m})$; **[2]**

*This question is worth **[2]**, but it is easy to accidently award **[1]**.*

(c) according to the spacecraft observer, the space station observer receives light from B and F at the same time;
for the spacecraft observer the space station observer moves away from the waves from B/towards the waves from F;
but the speed of light is constant;
according to the spacecraft observer light from B must be emitted first; **[4]**
*Do not award second marking point for answers that refer to light the spacecraft observer SEES or to distances to the spacecraft.*

**15.** (a) (i) to measure the speed of the Earth relative to the aether;
to verify existence of the aether; **[1 max]**

(ii) to change the speed of light along the arms of the interferometer / to create a phase difference between the beams / to change speed of the Earth relative to the aether;
to obtain a shift in fringes; **[2]**

(b) there was a null result, suggesting speed of light is constant (in vacuum);
this is a postulate of (special) relativity; **[2]**

**16.** (a) change in total energy/kinetic energy is 1.5 GeV;
total energy is $1.5 + 0.938 = 2.4$ (GeV) ***or*** $3.8 \times 10^{-10}$ (J) ***or*** $3.9 \times 10^{-10}$ (J); **[2]**
*Award **[2]** for a bald correct answer.*

(b) $pc\left(= \sqrt{E^2 - [mc^2]^2}\right) = \sqrt{2.4^2 - [0.938]^2}$; *(allow ECF from (a))*
$p = 2.2$ ***or*** $2.3\,(\text{GeV}\,\text{c}^{-1})$ ***or*** $1.2 \times 10^{-18}\,(\text{kg}\,\text{m}\,\text{s}^{-1})$; **[2]**
*Award **[2]** for a bald correct answer.*

(c) $\gamma = \left(\frac{2.44\ \text{GeV}}{0.938\ \text{GeV}}\right) = 2.6$;
$u = \frac{p}{\gamma m_0} = \frac{2.25}{2.6 \times 0.938} = 0.92\text{c}$; *(allow ECF from (a) and (b))*

***or***

$\left(p = \gamma m_0 u = \gamma m_0 c^2 \frac{u}{c^2} \Rightarrow\right) u = \frac{pc}{E} c$;
$= \left(\frac{2.2}{2.4}\text{c} =\right) 0.92\text{c}$; *(allow ECF from (a) and (b))* **[2]**
*Award **[2]** for a bald correct answer.*

**17.** (a) there is a force of attraction between (the mass of) the Sun and (the mass of) the planet;
which acts as a central/centripetal force for the planet; **[2]**

(b) (mass of the) Sun curves/warps spacetime around it;
planets move in paths of shortest length/geodesic (in this curved/warped spacetime); **[2]**

**18.** (a) (i) any straight line with negative slope; **[1]**

(ii) a downward curve (projectile like); **[1]**

(b) $\Delta f = \left(f_{\text{detector}} - f_{\text{base}} = \frac{fgh}{c^2} =\right) \frac{3.4 \times 10^{18} \times 12 \times 25}{9.0 \times 10^{16}}$;
$= 1.1 \times 10^4$ (Hz);
negative sign/red-shifted; **[3]**
*Award **[3]** for a bald correct answer of $-1.1 \times 10^4$ (Hz).*

**Option I — Medical physics**

**19.** (a) (in the outer ear) sound causes the tympanic membrane/eardrum to vibrate;

(in the middle ear) the ossicles amplify the sound; } *(accept individual ossicle names)*

sound is transmitted to the oval window;
(in the inner ear) sound is transferred as a pressure wave in the liquid filled cochlea;
frequency discrimination takes place within the cochlea;
nerve cells are stimulated carrying the information to the brain (via the auditory nerve); **[4 max]**
*Do not award marks simply for reference to parts of the ear, look for physical processes.*

(b) (i) $\left(I = \frac{0.12 \times 10^{-6}}{65 \times 10^{-6}}\right) = 1.8 \times 10^{-3}\ (\text{W m}^{-2})$; **[1]**

(ii) $(\text{IL} =) 10 \lg \frac{1.8 \times 10^{-3}}{1.0 \times 10^{-12}}$; *(allow ECF from (b)(i))*
$\approx 93\,(\text{dB})$; **[2]**
*Award **[2]** for a bald correct answer.*

(c) equal increases in the sensation of loudness involve equal <u>ratios</u> of intensities; } *(ratios needed)*

and the given intensities have the same ratio $\left(\frac{0.60}{0.12} = \frac{3.0}{0.60}\right)$; **[2]**

***or***

change in sensation of loudness is logarithmic / related to change in intensity <u>level</u>;
both changes result in the same increase in intensity level / an increase of 7 dB in intensity level;

**20.** (a) (i) the absorption of energy/loss of power from the beam; **[1]**

(ii) correct substitution $\frac{I_0}{2} = I_0 e^{-\mu x_{\frac{1}{2}}}$;

taking natural logs $\ln\frac{1}{2} = -\mu x_{\frac{1}{2}}$;

$\left(\ln 2 = \mu x_{\frac{1}{2}}\right)$ **[2]**

*Answer given, marks are for correct working.*

(iii) $\mu = \left(\frac{\ln 2}{0.73} = \right) 0.95\,\text{cm}^{-1}$;

$I = \left(I_0 e^{-0.95\times 2.0} = \right) 0.15\, I_0$; **[2]**

***or***

number of half-value thicknesses $= \frac{2}{0.73} = 2.74$;

$I = 0.5^{2.74} = 0.15\, I_0$;

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

(b) X-ray is a single exposure, a CT involves many exposures from different angles;
X-ray is a 2D image, a CT is a 3D image;
X-ray involves much less radiation to the patient compared to that of a CT;
CT requires (fast) computer processing, not essential for an X-ray; **[3 max]**

**21.** (a) the product of the speed of sound and the density of the medium/substance; **[1]**
*Accept as an equation with symbols defined.*

(b) (i) *The data is on the previous page and most candidates do not realize it is to be used here. So two alternative MS are given which try to be fair to all candidates.*

the impedance of gel and soft tissue are the <u>same</u>;
so the equation gives a reflection coefficient (OWTTE) of zero; **[2]**

***or*** *(knowledge based answer)*

gel replaces air which would cause unwanted reflection / air has a lower impedance than soft tissue;
the impedance of gel and soft tissue are the same/similar so reflection is reduced;
*Do not reward bald "reflection will be less/reduced" for the second marking points as this is given in the question.*
*Do not accept "density" instead of impedance.*

(ii) $\left(\left[\frac{6.1\times10^6-1.6\times10^6}{6.1\times10^6+1.6\times10^6}\right]^2\right)=0.34$ ; **[1]**

(iii) intensity reaching bone is $0.40\,I_0$ ;

intensity reflected from bone is $0.34\times0.40\,I_0$ ; } *(allow ECF from first marking point)*

intensity reaching transducer is $(0.40\times0.34\times0.40\,I_0)=0.054\,I_0$ ; **[3]**

*Award **[2 max]** for an answer of* $0.16\,I_0$ ***or*** $0.12\,I_0$.
*Award **[3]** for a bald correct answer.*

**22.** (a) (i) energy absorbed per unit mass; *(accept equation with all symbols defined)* **[1]**

(ii) the absorbed dose / energy absorbed per unit mass times the quality factor of radiation; } *(accept equation with all symbols defined)* **[1]**

(b) (i) the time for the activity to halve due to <u>physical and biological</u> processes / *OWTTE*; **[1]**

***or***

the time taken for the activity <u>inside</u>/<u>within</u>/<u>in</u> the patient to halve;
*Do not reward the standard definition of half-life without the idea of the underlined terms.*
*Accept effective half-life equation with all symbols defined.*

(ii) energy released is $(0.25\times10^6\times3.1\times10^6\times1.6\times10^{-19}\times8.0\times3600=)3.57\times10^{-3}$ (J);

absorbed dose is $\frac{3.57\times10^{-3}}{0.018}=198$ (mGy);

$198\times1=200$ (mSv); **[3]**

*The last marking point can be awarded as ECF from the previous marking point if the* $\times1$ *is explicit.*
*Award **[2 max]** for answer of* $6.9\times10^{-6}$ *(Sv) caused by missing time of 8 hours.*
*Award **[3]** for a bald correct answer.*

**Option J — Particle physics**

**23.** (a) (i) a particle with the same mass but opposite quantum numbers/charge; **[1]**

(ii) the neutron has baryon number $+1$, so the antineutron has baryon number $-1$;
so they are different; **[2]**

***or***

the neutron consists of three quarks (udd) and the antineutron consists of three antiquarks $(\bar{u}\bar{d}\bar{d})$;
so they are different;
*Award **[0]** for a bald correct answer.*

(b) (i) a short lived/virtual particle/(gauge) boson;
that transfers energy/momentum/force between interacting particles; **[2]**

(ii) $W^-$; **[1]**

(iii) zero; **[1]**

(iv) $\Delta S = 0-(-1) = +1$; **[1]**

(c) $\left(R = \frac{h}{4\pi mc} \Rightarrow\right) m = \frac{h}{4\pi cR}$; *(the mark is for rearrangement)*

$m\left(= \frac{6.63\times10^{-34}}{4\pi\times3\times10^{8}\times10^{-15}}\right) \approx 1.8\times10^{-28}$ (kg); **[2]**

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

**24.** (a) *advantage*: simple machines / less bremsstrahlung/braking radiation/radiation losses;
*disadvantage*: energy limited / time of collision cannot be varied; **[2]**

(b) $E_A = 2\times938+135 = 2011$ (MeV);

$E_{total} = \left(\frac{{E_A}^2 - 2[m_p c^2]^2}{2m_p c^2} = \right)1218$ (MeV); *(allow ECF)*

$E_K = (1218-938=)\ 280$ (MeV) ***or*** $4.49\times10^{-11}$ (J); *(allow ECF)* **[3]**

*Award **[3]** for a bald correct answer.*

(c) the accelerated protons lose energy due to bremsstrahlung/braking radiation/radiation losses;
(so additional energy is needed) **[1]**

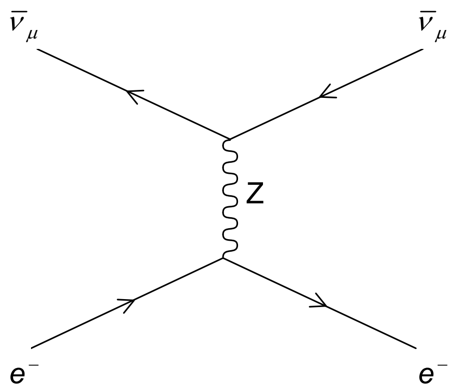
***or***

to provide kinetic energy for the outgoing particles;

**25.** (a) (i) electron lepton number/muon lepton number/family lepton number; **[1]**
*Do not accept just "lepton number" as this **is** conserved.*

(ii) electric charge; **[1]**

(b)




arrows for $e^-$ point forward in time and arrows for $\bar{\nu}_\mu$ point backwards in time;
vertices $\bar{\nu}_\mu Z \bar{\nu}_\mu$ and $e^- Z e^-$; *(inspect carefully, many draw $e^- Z \bar{\nu}_\mu$ vertices)*
Z particle; **[3]**
*Award each marking point independently.*
*Award **[2 max]** if the diagram is rotated $90^\circ$.*
*Allow particles to be expressed in words.*

(c) (i) two identical fermions cannot occupy the same quantum state; **[1]**
*Also accept any named fermion, eg: electron.*

(ii) the three u quarks each have different colour; **[1]**

(iii) hadrons have no colour/colour charge of zero;
so cannot be composed of three quarks of the same colour / are composed of quarks of different colour; **[2]**

***or***

if they did the hadron would have colour;
violating confinement which states that isolated colour cannot be observed;
*Award **[0]** for bald "not possible".*

**26.** (a) $\frac{3}{2}kT = 2mc^2$; *(allow use of kT)*

$T = \left(\frac{4mc^2}{3k} = 8 \times 10^9 = \right) 10^{10}$ (K); **[2]**

*Award **[1 max]** for an answer of $4 \times 10^9$ K for use of single electron mass.*

(b) there were slightly more particles than antiparticles in the early universe;
temperature cooled to a point at which spontaneous pair production became impossible;
pair annihilation removed the remaining antiparticles; **[3]**