M11/4/PHYSI/HP3/ENG/TZ1/XX/M

International Baccalaureate®
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MARKSCHEME

May 2011

PHYSICS

Higher Level

Paper 3

20 pages

General Marking Instructions

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. Do **not** award more than the maximum marks allowed for part of a question.

2. Each marking point has a separate line and the end is signified 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 <u>underlined</u> 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 writing ***OWTTE*** (or words to that effect).

8. 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.

9. Only consider units at the end of a calculation.

10. Significant digits should only be considered in the final answer. Deduct **1 mark in the paper** for an **error of 2 or more digits** unless directed otherwise in the markscheme.

e.g. if the answer is 1.63:

2	*reject*
1.6	accept
1.63	accept
1.631	accept
1.6314	*reject*

Option E — Astrophysics

E1. (a)

Nearest the Sun	Venus
↓	Mars
	Jupiter
Furthest from the Sun	Neptune

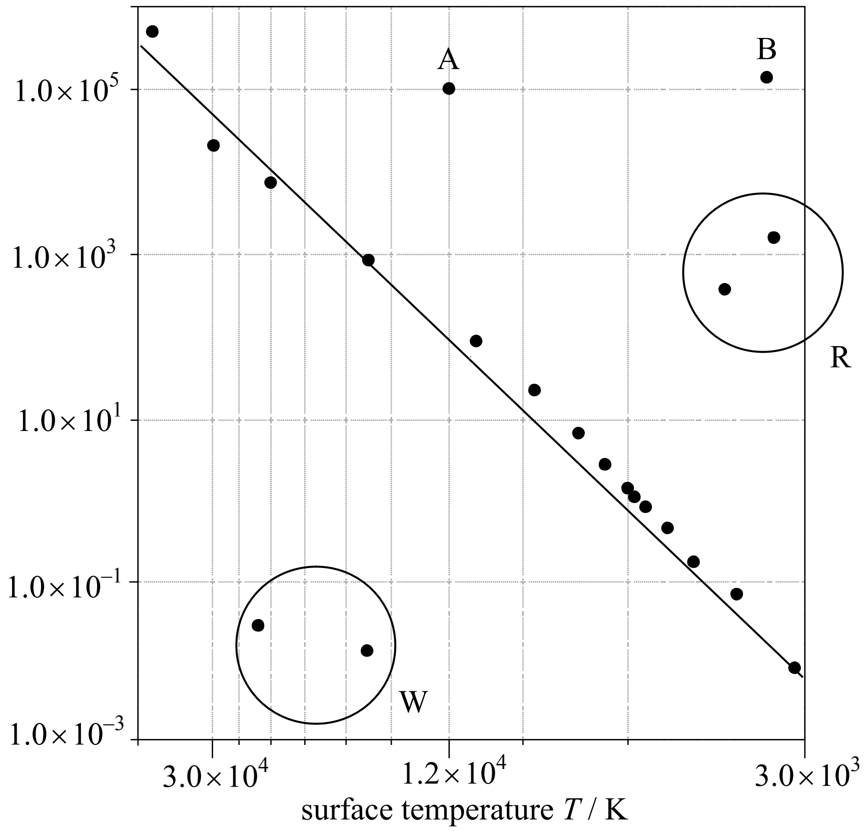
*Award **[2]** for all correct and **[1]** for two correct.* ***[2]***

(b)

Largest diameter	Jupiter
↓	Neptune
	Venus
Smallest diameter	Mars

*Award **[2]** for all correct and **[1]** for two correct.* ***[2]***

E2. (a)



(i) circle labelled R as shown above; ***[1]***
Accept answers that include the star B within the circle.

(ii) circle labelled W as shown above; ***[1]***

(iii) any line (not necessarily straight) going from top left to bottom right, through or near all or most of stars; ***[1]***

(b) star B has lower temperature;
star B has (slightly) larger luminosity / stars have approximately same luminosity;
surface area calculated from $L=\sigma AT^4$, so star B has larger surface area/diameter / to give the same/similar luminosity at lower temperature, star B must have bigger diameter/surface area; ***[3]***

(c) (from HR diagram) $L_A = 10^5 L_S$;

$b = \dfrac{L}{4\pi d^2}$ used;

to give $\dfrac{d_A}{d_S} = \sqrt{\dfrac{L_A}{L_S}\times\dfrac{b_S}{b_A}} = \sqrt{10^5 \times \dfrac{1.4\times10^3}{4.9\times10^{-9}}}$;

hence $d_A = 1.7\times10^8$ AU;

$= 800$ pc ***[4]***

Do not award a mark for the conversion from AU to pc.

(d) the parallax angle is too small to be measured accurately / the distance is greater than the limit for stellar parallax, which is 100 pc; ***[1]***

Accept any value from 100–800 pc for limit. Do not accept "it's too far away".

E3. (a) the universe is expanding / many galaxies are moving away from us; *[1]*

(b) the CMBR fills all of space / is uniform / is distributed equally, consistent with an "explosion" (at start of universe);
the temperature of the radiation (2.7 K) is consistent with cooling due to expansion/redshift; *[2]*

(c) $\lambda_{max} = \frac{2.9\times10^{-3}}{T} \Rightarrow T = \frac{2.9\times10^{-3}}{7.0\times10^{-7}}$;
$T = 4100$ K; *[2]*

E4. (a) $\frac{L_K}{L_S} = \left[\frac{m_K}{m_S}\right]^{3.5}$;

$m_K = \left[\frac{L_K}{L_S}\times m_S^{3.5}\right]^{\frac{1}{3.5}} = \left[2.0\times10^4\right]^{\frac{1}{3.5}} m_S = 16.9\,m_S$;
hence $m_K \approx 17 m_S$ *[2]*

(b) Khad will become a red supergiant/superred/superred giant;
a supernova will take place;
the core/remnant will form a neutron star or black hole; *[3]*

E5. (a) (i) recessional speed of a galaxy is directly proportional to distance from Earth / $v = H_0 d$ with symbols defined; *[1]*

(ii) local velocity of Andromeda relative to Earth greater than (recessional) speed due to expansion of universe / *OWTTE*; *[1]*

(b) (i) relative speed between two points in universe separated by distance d is $v = \frac{d}{T}$ where T is the age of the universe;
$v = \frac{d}{T} = H_0 d$ therefore $T = \frac{1}{H_0}$; *[2]*

(ii) $T = \frac{1}{80}\times\frac{10^6\times3.26\times9.46\times10^{15}}{1000} = 4\times10^{17}\,(\text{s})$; *[1]*
Do not deduct unit mark if seconds not given, as question asks for answer in seconds.

Option F — Communications

F1. (a) (i) 100 kHz; *[1]*

(ii) 4 kHz; *[1]*

(iii) 8 kHz; *[1]*

(b) (i) *AM*: *e.g.* signal information encoded in a variation of the carrier signal's amplitude / *OWTTE*;
FM: *e.g.* signal information encoded in a variation of the carrier signal's frequency / *OWTTE*; *[2]*
*Award **[0]** for restating amplitude modulation and frequency modulation. The answer needs to explain "modulation". Accept good labelled diagrams as explanation.*

(ii) *Advantage*: not as susceptible to noise / quality better / less fading;
Disadvantage: larger bandwidth needed / more complex circuitry / limited range of broadcast; *[2]*

F2. (a) analogue; *[1]*

(b) sample / hold; *[1]*

(c) realisation that S_1 is 8 bit whereas S_2 is 4 bit;
therefore quality of reproduction of S_1 > quality of reproduction of S_2; *[2]*

(d) (i) definition equation $\left(=10\lg\frac{I_1}{I_2}\right)$ and definition of symbols / the loss of power of a signal (with distance travelled) / *OWTTE*; *[1]*

(ii) $\text{attenuation} = 10\lg\left[\frac{1}{100}\right] = -20\,\text{dB}$;

$\text{length} = \frac{-20}{-4} = 5\,\text{km}$; *[2]*

(iii) amplification;
reshaping; *[2]*

F3. (a) microwave; *[1]*

(b) permanent link not possible;
requires tracking; *[2]*

(c) cultural judgement involved in what is and what is not acceptable to broadcast / how does one decide what is and what is not acceptable; *[1]*
Accept any sensible and appropriate comment.

F4. (a) infinite (open loop) gain;
no current drawn on input / infinite input resistance/impedance; *[2]*

(b) switchover happens when non-inverting input $\geq 3\,\text{V}$;
current through $100\,\text{k}\Omega = \frac{3-[-13]}{100\times10^3} = \frac{16}{100\times10^3} = 0.16\,\text{mA}$;
$V_{IN} = 3 + [0.16\,\text{mA} \times 22\,\text{k}\Omega] = 3 + 3.52 = 6.5\,\text{V}$; *[3]*
*Award **[2 max]** for calculating other threshold value i.e. 0.8V.*

(c) idea that noise and/or dispersion distort digital pulse;
idea of two fixed outputs with different switch over points;
link to cleaning up of signal / removal of noise / no stray pulses produced; *[3]*

F5. (a) new base station selected and connected; *[1]*

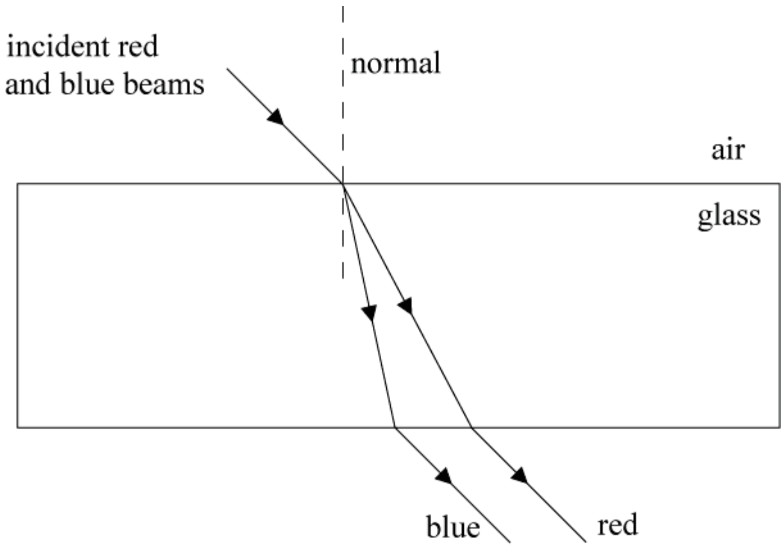
(b) no change; *[1]*

Option G — Electromagnetic waves

G1. (a) any value within the range 320 – 780 nm; *[1]*

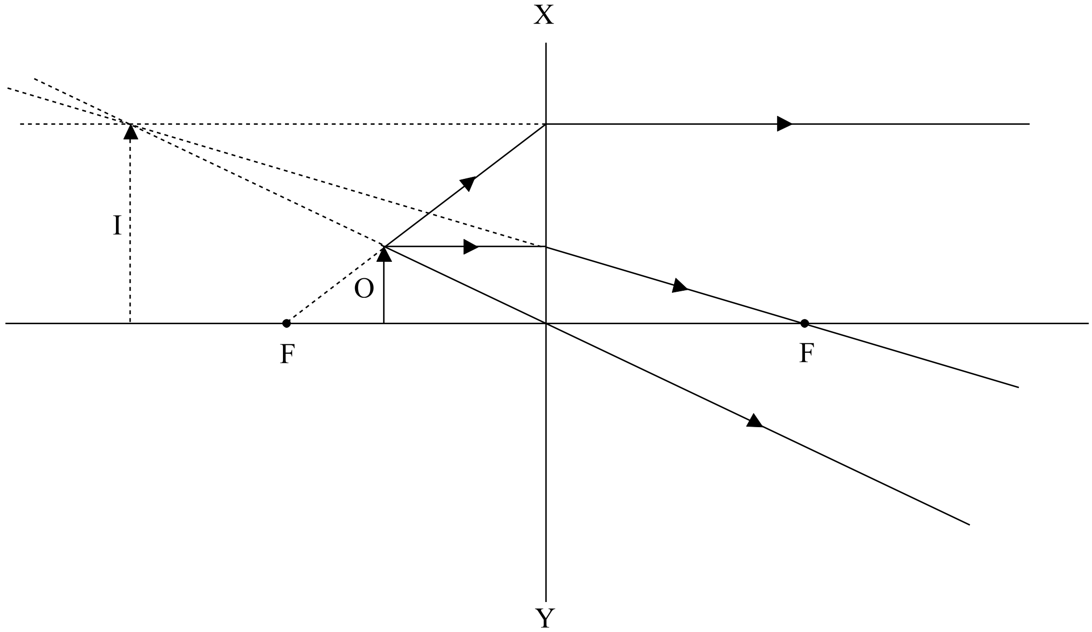
(b) splitting/separation into component colours/wavelengths/frequencies;
because different colours/wavelengths/frequencies have different refractive indices / refract by different amounts; *[2]*

(c) refraction towards normal for both rays at first surface, blue ray refracted more than red ray;
both rays refracted away from normal at second surface, both emergent rays parallel to incident beam; *[2]*
See diagram below. Judge answers by eye.



G2. (a) (i) the point on the principal axis;
through which parallel rays pass after going through the lens / from which rays are parallel after passing through the lens; ***[2]***

(ii)



any two correct rays out of the three shown above;
image correctly located and labelled; ***[3]***

(iii) virtual because no rays pass through the image / image cannot be formed on a screen; ***[1]***
Mark is for explanation, not for statement of virtual.

(b) (i) $\frac{1}{f}=\frac{1}{D}+\frac{1}{u}\Rightarrow\frac{1}{u}=\frac{1}{5.0}-\left[-\frac{1}{25}\right]$;
$\frac{1}{u}=\frac{5+1}{25}=\frac{6}{25}\Rightarrow u=4.2\,\text{cm}$; ***[2]***

(ii) $m=\frac{D}{f}+1=\frac{25}{5.0}+1=6$ ***or*** $m=-\frac{D}{u}=-\left[\frac{-25}{4.167}\right]=6$;
$m=\frac{h_i}{h_o}\Rightarrow h_i=mh_o=6.0\times0.80=4.8\,\text{cm}$; ***[2]***

*Award **[4]** for (b)(i) and (b)(ii) on a scale diagram with the points shown below.*

suitable scale identified;
correct placement of principal axis, lens and object;
correct rays to enable location of image;
correct measurements for both answers;
Award final mark for correct answers based on diagram (judge by eye).

G3. (a) $d = \dfrac{1}{8.00 \times 10^5} = 1.25 \times 10^{-6}\,\text{m}$;

$d \sin\theta = n\lambda \Rightarrow \theta = \sin^{-1}\left[\dfrac{n\lambda}{d}\right]$;

$\sin^{-1}\left[\dfrac{2 \times 589 \times 10^{-9}}{1.25 \times 10^{-6}}\right] = 70.5^\circ$, $\sin^{-1}\left[\dfrac{2 \times 590 \times 10^{-9}}{1.25 \times 10^{-6}}\right] = 70.7^\circ$;

$70.7^\circ - 70.5^\circ = 0.2^\circ$; ***[4]***

(b) the lines are closer together / not clearly separate in the first order spectrum; ***[1]***

G4. (a) $\lambda_{\text{min}} = \dfrac{hc}{eV} = \dfrac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{1.6 \times 10^{-19} \times 15000}$;

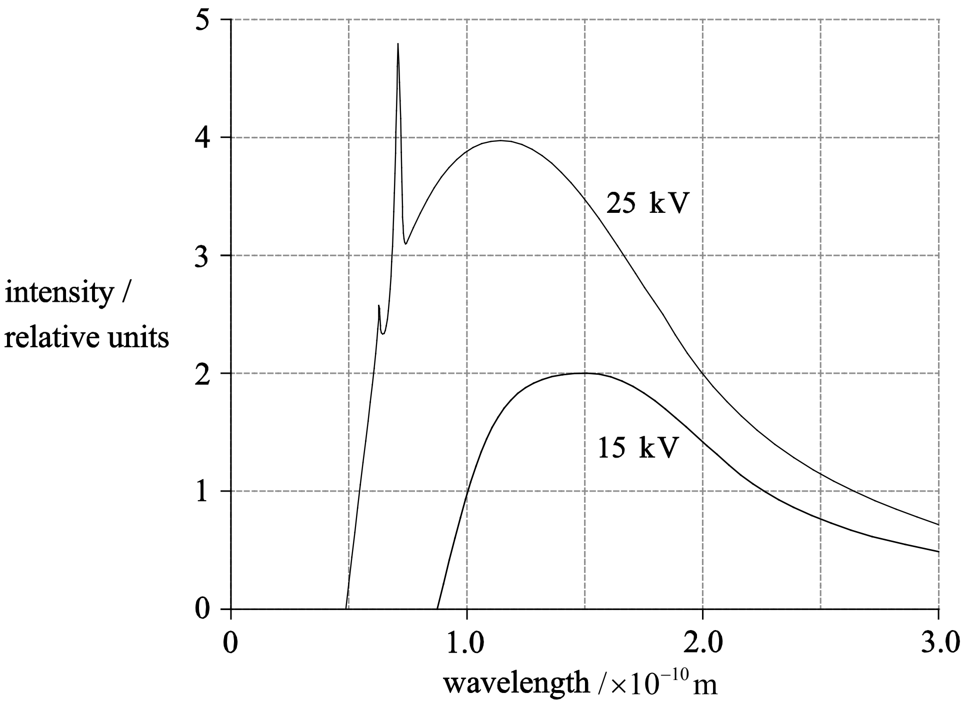
$= 8.3 \times 10^{-11}\,\text{m}$;

or

from graph, λ_{min} is $0.5 \times 10^{-10}\,\text{m}$;

since ratio of voltages is $\dfrac{25}{15}$, new λ_{min} is $0.50 \times 10^{-10} \times \dfrac{25}{15} = 8.3 \times 10^{-11}\,\text{m}$; ***[2]***

(b) graph starting at approximately 0.83 on x-axis;
continuous spectrum with peak to the right and below 25 kV graph;
no characteristic spectra; ***[3]***
See graph below.



Apply ECF throughout question G4. In particular, graph in (b) needs to be consistent with answer to (a).

G5. (a) phase change of π occurs on reflection at one slide but not the other;
constructive interference occurs when path difference between two reflected rays is $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ etc;
the extra distance travelled is twice the thickness of the air (wedge) hence $2t = \left[m + \frac{1}{2}\right]\lambda$; ***[2 max]***

(b) number of fringes $= \frac{82}{1.2} = 68$;
fringe separation corresponds to a change in thickness of $\frac{\lambda}{2}$;
thickness of paper $= 68 \times \frac{590 \times 10^{-9}}{2} = 2.0 \times 10^{-5}$ m; ***[3]***

Option H — Relativity

H1. (a) the length of an object as measured by an observer who is at rest relative to the object; *[1]*

(b) (i) $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-0.75^2}} = 1.5$; *[1]*

(ii) $L = \frac{L_0}{\gamma} = \frac{240}{1.5} = 160\,\text{m}$; *[1]*

(iii) $L_0 = \gamma L = 1.51 \times 200 = 300\,\text{m}$; *[1]*

(iv) the spaceship is never completely inside the tunnel;
because (according to observer B) the spaceship is longer than the tunnel; *[2]*
Apply ECF in all parts of question (b).

(c) observer B will not see the two flashes simultaneously;
according to B, light 2 is moving to the left/towards observer B;
since the speed of light is the same for both sources;
the flash from light 2 reaches B before the flash from light 1;

or

according to B, the two flashes arrive at A simultaneously;
according to B, A is moving to the left/away from light 2;
since light from both sources moves with the same speed;
for the flashes to be received by A at the same time, the flash from light 2 must be emitted first; *[4]*
Accept any equivalent discussion.

H2. (a) (i) $u_x' = u_x + v = 0.60c + 0.80c = 1.40c$; ***[1]***

(ii) $u_x'\left(= \dfrac{u_x + v}{1 + \dfrac{u_x v}{c^2}}\right) = \dfrac{0.60c + 0.80c}{1 + \dfrac{0.60c \times 0.80c}{c^2}}$;

$\left(= \dfrac{1.40c}{1.48}\right) = 0.95c$; ***[2]***

*Award **[1]** for answers that use $v = -0.80c$ to get an answer of $-0.38c$.*

(b) the answer to (a)(i) exceeds *c* / the answer to (a)(ii) does not exceed *c*;
hence the Galilean transformation is not valid / the relativistic transformation must be used / *OWTTE*; ***[2]***

(c) $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}} = \dfrac{1}{\sqrt{1 - \dfrac{0.80^2 c^2}{c^2}}} = 1.7$;

$E_K = [\gamma - 1] m_0 c^2 = [1.667 - 1] \times 1.0 \times 10^3 \times [3.0 \times 10^8]^2$;

$= 6.0 \times 10^{19}$ J; ***[3]***

*Award **[0]** for answers that use $E_k = \frac{1}{2}mv^2$ to get an answer of 2.9×10^{19} J.*

H3. (a) light from two beams causes an interference pattern at the detector/telescope;
due to the path difference/difference in speed of light relative to aether between two beams;
if the apparatus were rotated (by 90 degrees) the interference pattern would change/shift (if the aether existed);
the amount of shift/change would allow the speed of the Earth (relative to the aether) to be determined; ***[4]***

(b) the orientation of the apparatus had no effect on the interference pattern;
hence the speed of light does not depend on the speed of the source/speed of observer / there is no absolute reference frame / aether does not exist; ***[2]***

H4. (a) (i) observer B measures a lower frequency; *[1]*

(ii) $\frac{\Delta f}{f} = \frac{g\Delta h}{c^2} \Rightarrow \Delta f = \frac{4.62\times10^{14}\times9.81\times1.00\times10^{2}}{\left[3.00\times10^{8}\right]^{2}}$;

$\Delta f = 5.04\,\text{Hz}$; *[2]*

Accept use of $g = 10\ \text{ms}^{-2}$ *to get* $f = 5.13$ Hz.

(iii) assume that g is constant over the height interval; *[1]*

(b) the equivalence principle states that it is impossible to distinguish between an accelerating reference frame and a gravitational field;
therefore the frequency measured by observer D will be lower than that measured by observer C (by 5.04 Hz) / observer C measures the same value as A, observer D measures the same frequency as B / *OWTTE*; *[2]*

Option I — Medical physics

I1. (a) *Intensity*: defining equation and definition of symbols $I = \frac{P}{A}$;

Intensity level: defining equation and definition of symbols $IL = 10\lg\frac{I}{I_0}$, where

$I_0 = 1.0 \times 10^{-12}\ \text{Wm}^{-2}$ / threshold of hearing; ***[2]***

(b) (i) realisation/statement/implication that noisiest location is C;

$IL = 10\lg\left[\frac{891 \times 10^{-3}}{1.0 \times 10^{-12}}\right]$;

$= 119\,\text{dB}$; ***[3]***

Apply ECF for candidates working with a reading from a different location.

(ii) yes since this is near the threshold of pain;
threshold of pain is 120 dB / intensity level above comfort level; ***[2]***

(iii) (constant) ringing/buzzing/noise in the ears / *OWTTE*; ***[1]***

I2. (a) (i) X-rays cause ionisations;
which could cause cell damage / increased risk of cancer; ***[2]***

(ii) intensifying screen placed next to the film;
X-rays absorbed by screen and energy re-radiated as light to film; ***[2]***

(iii) barium meal;
to increase contrast between inside and outside the intestine; ***[2]***

(b) (i) density of material × speed of ultrasound in material; ***[1]***

(ii) $\text{kg}\,\text{m}^{-2}\text{s}^{-1}$; ***[1]***

(iii) strong reflections take place where there is a large change in acoustic impedance;
gel eliminates air gap between source/receiver of ultrasound and skin surface / acoustic impedance of gel matches that of skin (and source/receiver); ***[2]***

(c) (i) laser energy focused into small area;
temperature made very high, therefore cutting of tissue is possible; ***[2]***

(ii) idea that endoscope is inserted (through mouth into stomach);
idea that light (either for observation or laser) travels along the optic fibre to blockage; ***[2]***

Accept context of optic fibre used to image blockage and/or path for laser.

I3. (a) $D=\frac{H}{Q}=\frac{25}{1}=25\left(\text{m J kg}^{-1}\right)$;

$D=\frac{E}{m}\rightarrow E=mD=75\times 25\left(\text{m J}\right)$;

$=1.9\text{ J}$; ***[3]***

(b) no since amount of energy relatively small / *OWTTE*; ***[1]***

Answer and appropriate justification needed for mark.

(c) (i) risk of not identifying condition;

needs to be balanced against the small risk of developing cancer; ***[2]***

(ii) idea that film badge monitors exposure over length of time;

so that exposure can be kept within agreed limits; ***[2]***

*Award **[0]** for answers that imply that the film badge prevents or protects against an increase dose without including concept of monitoring.*

Option J — Particle physics

J1. (a) a particle that mediates/carries/transmits one of the fundamental forces / a particle that is exchanged between two particles when undergoing one of the fundamental interactions / *OWTTE*; ***[1]***

(b) $R \approx \frac{h}{4\pi mc} \Rightarrow m \approx \frac{6.63 \times 10^{-34}}{4\pi \times 1.5 \times 10^{-15} \times 3 \times 10^{8}}$;
$\approx 1.2 \times 10^{-28}$ kg; ***[2]***

(c) π^{+};
from conservation of charge at either vertex, the pion must have charge of +1; ***[2]***

(d) 0 or 1;
mesons consist of one quark and one anti-quark (which have spin $\pm\frac{1}{2}$);
the spins can be parallel (giving 1) or antiparallel (giving 0) / $\frac{1}{2} + \frac{1}{2} = 1$ and $\frac{1}{2} - \frac{1}{2} = 0$ / *OWTTE*; ***[3]***

(e) all hadrons are colourless;
not possible for two quarks to cancel out colour / *OWTTE*;

or

particle with two up quarks would have baryon number of 2/3;
not possible as baryon number needs to be –1, 0 or 1 / *OWTTE*;

or

particle with two up quarks would have charge $+\frac{4}{3}$;
not possible as charge has to be an integer / a whole number (or zero); ***[2]***

J2. (a) every half revolution, the particles travel across the gap in opposite directions; so the force must be reversed in order to always speed up particles; *[2]*

(b) $qvB = \frac{mv^2}{r} \Rightarrow v = \frac{qBr}{m}$;

$v = \frac{2\pi r}{T} \Rightarrow T = \frac{2\pi m}{qB}$;

$f = \frac{1}{T} = \frac{qB}{2\pi m}$; *[3]*

(c) maximum particle energy for a cyclotron is less;
a single cyclotron can only be used with stationary targets / only one beam can be produced at a time / cyclotrons cannot have storage rings; *[2]*

(d) particles moving at higher speeds have more energy;
mass can be created from the energy (according to $E = mc^2$); *[2]*

(e) alpha particles have greater mass, so greater momentum at same speed;
from $p = \frac{h}{\lambda}$, the greater the momentum, the smaller the wavelength;
the smaller the wavelength, the better the resolution; *[3]*

J3. (a) total energy at start $=$ total energy at end $= 4 \times 938\,\text{MeV} = 3752\,\text{MeV}$;

E_K of one proton $= \frac{3752 - (2 \times 938)}{2} = 938\,\text{MeV}$; *[2]*

(b) baryon number is conserved;
$1 + 1 \neq 1 - 1 + 1$, so not possible; *[2]*

J4. (a) $E_K = \frac{3}{2}kT \Rightarrow T = \frac{2E_K}{3k} = \frac{2 \times 28 \times 1.6 \times 10^{-19} \times 10^6}{3 \times 1.38 \times 10^{-23}}$;

$\text{T} = 2.2 \times 10^{11}\,\text{K}$; *[2]*

(b) in the standard model the fundamental building blocks of matter are point particles but in string theory they are extended objects;
the standard model is formulated in three/four dimensions – string theory requires many extra dimensions / *OWTTE*; *[2]*