N10/4/PHYSI/HP3/ENG/TZ0/XX/M

International Baccalaureate®
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MARKSCHEME

November 2010

PHYSICS

Higher Level

Paper 3

20 pages

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

2. 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.**

3. Sometimes, careful consideration is required to decide whether or not to award a mark. In these cases write a brief annotation to explain your decision. You are encouraged to write comments where it helps clarity, especially for moderation and re-marking. It should be remembered that the script may be returned to the candidate.

4. Unexplained symbols or personal codes/notations are unacceptable.

5. Record marks in the right-hand margin against each mark allocation shown in square brackets *e.g.* ***[2]***. The total mark for a question must equal the number of ticks for the question.

6. Do **not** circle sub-totals. **Circle the total mark** for the question in the right-hand margin **at the end of the question.**

7. Where an answer to a part question is worth no marks, put a zero in the right-hand margin next to the square bracket.

8. Where work is submitted on additional sheets the marks awarded should be shown as ticks and a note made to show that these marks have been transferred to the appropriate square bracket in the body of the script.

9. For each Option: Add the totals for each question in the Option and write it in the Examiner column on the cover sheet.
Total: Add the marks awarded and enter this in the box marked TOTAL in the Examiner column on the cover sheet.

10. After entering the marks on the cover sheet check your addition to ensure that you have not made an error. Check also that you have transferred the marks correctly to the cover sheet. **All scripts are checked and a note of all clerical errors will be given in feedback to examiners.**

11. If an answer extends over more than one page and no marks have been awarded on a section draw a diagonal line through that section to indicate that it has been marked.

12. If a candidate has attempted more than the required number of questions within a paper or section of a paper, mark all the answers and use the marks of those answers that have the highest mark, **even if the candidate has indicated the question(s) to be marked on the cover sheet**.

13. A mark should not be awarded where there is contradiction within an answer. Make a comment to this effect in the left-hand margin.

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. 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. Indicate this with **ECF** (error carried forward).

10. Only consider units at the end of a calculation. Unless directed otherwise in the markscheme, unit errors should only be penalized once in the paper. Indicate this by writing **–1(U)** at the first point it occurs and **U** on the cover sheet.

11. 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*

Indicate the mark deduction by writing **–1(SD)** at the first point it occurs and **SD** on the cover sheet.

Option E — Astrophysics

E1. (a) *constellation*:
a collection/group of stars that form a recognizable pattern (as viewed from Earth) / a group/pattern of stars not close together (in space);

stellar cluster:
a group of stars (including gas and dust) held together by gravity/forming a globular/open arrangement / a group of stars close to each other (in space); ***[2]***

(b) (i) the apparent magnitude of P_A is (much) smaller than that of P_B;
in the apparent magnitude scale the smaller the magnitude the brighter the star; ***[2]***
Accept argument in terms of P_B being fainter than P_A.

or

apparent brightness of P_A is greater than P_B;
apparent brightness is intensity at surface of Earth;

(ii) the absolute magnitude of P_A is smaller than that of P_B;
the absolute magnitude is the apparent magnitude at a distance of 10 pc (from Earth);
so at the same distances from Earth P_A is much brighter than P_B so must be more luminous; ***[3]***
Accept argument in terms of P_B being fainter than P_A.

or

absolute magnitude of P_A is less than absolute magnitude of P_B;
absolute magnitude is a measure of luminosity;
lower values of absolute magnitude refer to brighter/more luminous star;

or

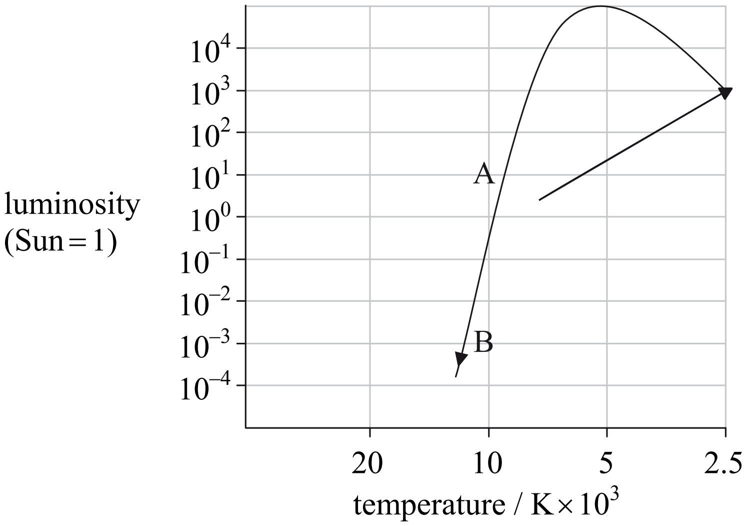
Accept answer based on answer to (c).
distances are the same from (c);
since $L = 4\pi d^2 b$ P_A is brighter than P_B;

(c) $m - M$ for $P_A = -2.28$ and $m - M$ for $P_B = -2.30$;
since $m - M = 5\lg\frac{d}{10}$ then d for each is very nearly same; ***[2]***
Accept answer based on calculation of individual d's (~ 3.5 pc).

(d) same distance from Earth <u>and</u> in the same region of space; ***[1]***

(e) recognize that the ratio of the luminosities is the same as the ratio of apparent brightness;
$\frac{L_A}{L_B} = \left(\frac{2.06 \times 10^{-8}}{1.46 \times 10^{-12}} = \right) 1.41 \times 10^4$; ***[2]***

(f)



(i) $P_A \rightarrow$ 10 000 K at 10; *(labelled A)* **[1]**

(ii) $P_B \rightarrow$ 10 000 K at 10^{-3}; *(labelled B)* **[1]**

(g) white dwarf; **[1]**
Allow ECF from diagram.

(h) to the red giant region (approximately either side of $L = 10^2$ and $T = 2500\,\text{K}$); *(judge by eye)*
to the white dwarf region (approximately either side of $L = 10^{-2}$ and $T = 10\,000\,\text{K}$); *(judge by eye)* **[2]**

(i) $\frac{150}{1} = \left(\frac{M_R}{1}\right)^{3.5}$ ***or*** $150 = M_R{}^{3.5}$;

evidence of algebraic manipulation *e.g.* $M_R = [150]^{\frac{1}{3.5}}$;

$= 4.2\,M_S$ **[2]**

*To award **[2]** there must be evidence of algebraic manipulation shown.*

(j) (i) neutron star; **[1]**

(ii) (because of) neutron degeneracy pressure / Pauli exclusion principle excludes further collapse; **[1]**

E2. (a) space and time originated from a single point in a large explosion / an expanding universe that originated from a single point / *OWTTE*; ***[1]***

(b) (i) temperature of the universe immediately after the Big Bang was very high;
as it expanded it cooled down;
the wavelength of the CMB corresponds to a temperature consistent with this cooling down / *OWTTE*;
red shift is due to expansion of universe; ***[3 max]***

(ii) indicates that the universe is expanding; ***[1]***

(c) the amount of red-shift enables the recession speed of a galaxy to be determined;
Hubble's law states that the recession speed is proportional to its distance from Earth/ $v = H_0 d$ with terms defined;
if the constant of proportionality/ H_0 is known then d can be determined; ***[3]***

(d) it is difficult to determine an accurate value of the Hubble constant / difficult to measure the red-shift / Hubble constant had different values in the past; ***[1]***

Option F — Communications

F1. (a) the modification/change of a carrier wave by addition/superposition of another signal wave; ***[1]***

(b) (i) 30 kHz; ***[1]***

(ii) 1.5 kHz; ***[1]***

(iii) difference between maximum and minimum displacement divided by two;
$\frac{2.8-1.1}{2}=0.85\,\text{V}$; *(accept answer in the range of 0.80 V to 0.90 V)* ***[2]***

(iv) 3.0 kHz; ***[1]***

(c) less susceptible to noise / better reception quality;
because noise gets added to amplitude in AM but in FM amplitude is constant; ***[2]***

F2. (a) speed of propagation depends on frequency/wavelength;
(and so after some time) different frequencies cover different distances; ***[2]***

(b) pulses will start to overlap (if bit-rate is too high); ***[1]***

(c) (i) pulse with longer duration and shorter height shown; ***[1]***

(ii) dispersion is caused by a range of signal frequencies/wavelengths;
so reduce range of frequencies/wavelengths / use monochromatic signal; ***[2]***

(d) (i) speed is $\frac{3.0\times10^{8}}{1.5}=2.0\times10^{8}\,\text{m s}^{-1}$;

and so time is $\frac{500\times10^{3}}{2.0\times10^{8}}=2.5\,\text{ms}$; ***[2]***

(ii) bit rate is $\left(\frac{1}{0.5\times10^{-9}}=\right)2.0\times10^{9}\,\text{Hz}$;

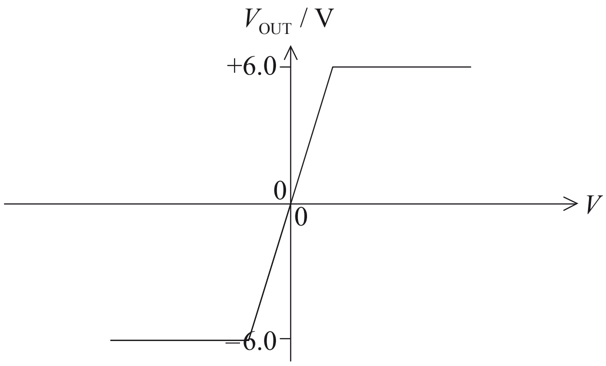
(since bit rate $=f\times$ number of bits,) $f=\frac{2.0\times10^{9}}{32}=62.5\,\text{MHz}$; ***[2]***

(e) an optical fibre might be preferable because the data are transmitted along a protected line;
in a satellite transmission the data can be intercepted by anyone; ***[2]***

or

a satellite is preferable provided that it has an encryption system/encoded signal;
wider coverage than cable / any other sensible suggestion;

F3. (a) (i) *Award marks for the graph as below with*:
constant value at -6.0 V for large negative voltages and constant value at $+6.0$ V for large positive voltages;
sharp linear rise to connect the two constant values; $\left\{\begin{array}{l}\textit{accept instantaneous}\\ \textit{transition}\end{array}\right.$ ***[2]***



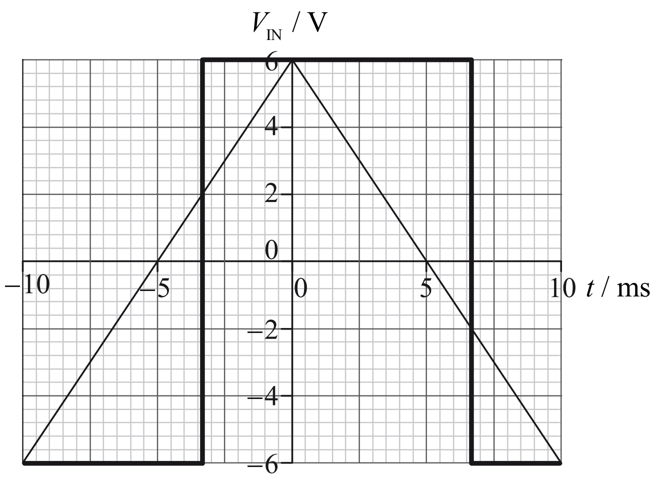
(ii) the output voltage changes abruptly from a low to a high value;
depending on whether the input voltage is smaller/larger than some reference voltage; ***[2]***

(b) (i) (switchover occurs when voltage in between resistors is 0 V with output at -6.0 V and so) current in 15 kΩ resistor is $I = \left(\frac{6}{15\times10^3} =\right) 4.0\times10^{-4}$ A ;
$V_{IN} = 5.0\times10^3 \times 4.0\times10^{-4}$;
$= 2.0$ V ***[2]***

or

p.d. across $15\,k\Omega = 6$ V ;
p.d. across $5\,k\Omega = \frac{5}{15}\times 6 = 2.0$ V ;

(ii) square wave pulse;
with verticals intercepting at +2.0 V and –2.0 V; ***[2]***



(c) digital signals are <u>distorted</u> (by noise/dispersion) during transmissions;
the Schmitt trigger <u>reshapes</u> the signals; ***[2]***

Option G — Electromagnetic waves

G1. (a) (i) (the waves) all have the same frequency/wavelength; *[1]*
Do not accept "one colour".

(ii) (the waves) are all in phase with each other / the phase difference between the waves is constant; *[1]*

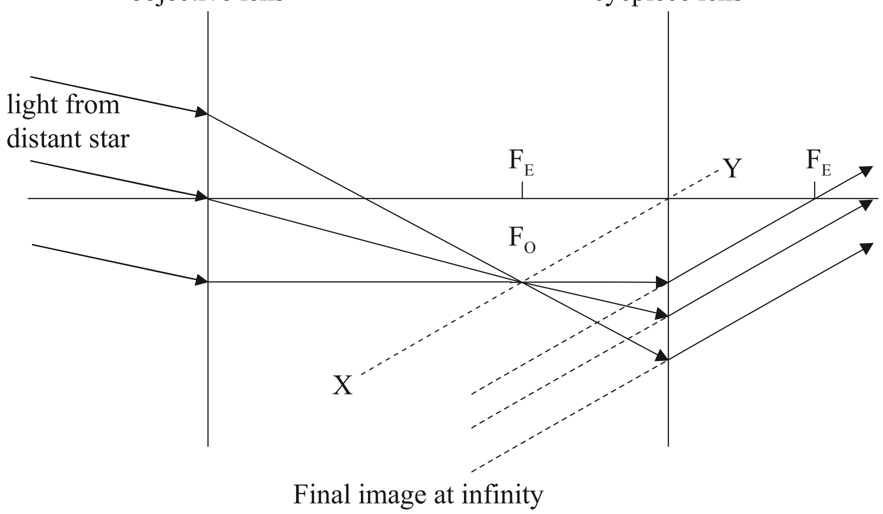
(b) (i) there are more electrons in the metastable state than in the ground state; *[1]*

(ii) from excited state to metastable state; *[1]*

(iii) from metastable state to ground state; *[1]*

(iv) $\lambda = \left(\frac{hc}{eV} = \right)\frac{6.6\times10^{-34}\times3.0\times10^{8}}{1.8\times1.6\times10^{-19}} = 6.9\times10^{-7}\ \text{m}$;
$= 690\,\text{nm}$ *[1]*

G2. (a)



(i) same distance to left of eyepiece as F_E is to the right; *(judge by eye)* *[1]*

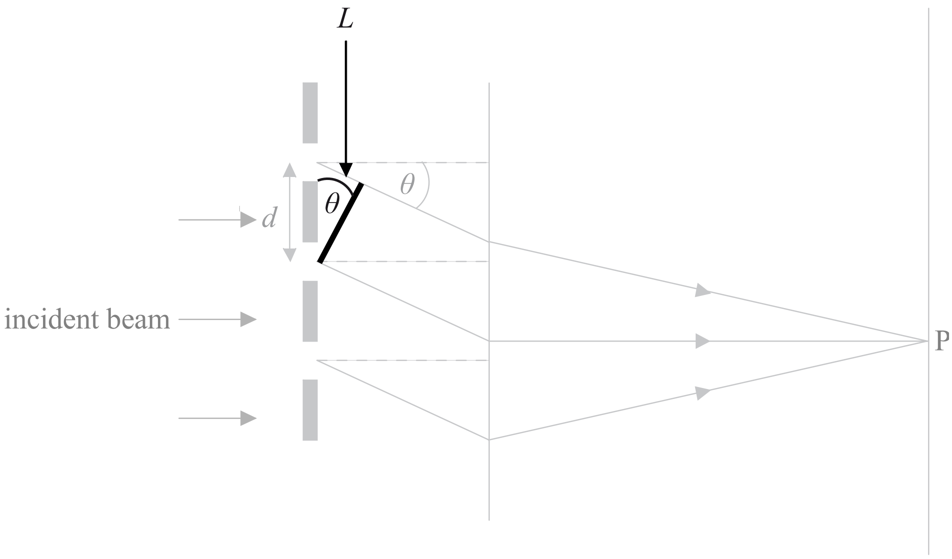
(ii) coincident with F_E as labelled in (a)(i); *[1]*

(iii) three rays meeting at focal plane of the two lenses;
construction line XY;
rays refracted at eyepiece;
extrapolation to indicate final image at infinity with label; *[3 max]*

(b) $f_e = \left(\frac{1}{40} = \right)2.5\,\text{cm}$ and $f_o = \left(\frac{1}{0.80} = \right)125\,\text{cm}$;
$M = \left(\frac{f_o}{f_e} = \right)\left(\frac{125}{2.5} = \right)50$; *[2]*

(c) *objective lens*: to eliminate/minimize chromatic aberration;
eyepiece lens: to eliminate/minimize spherical aberration; *[2]*

G3. (a) (i)

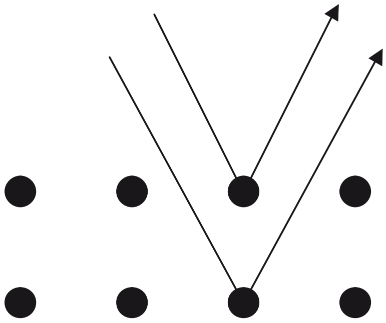


appropriate line and labelling of L and θ; ***[1]***

(ii) for constructive interference path difference = $n\lambda$ where n = 0, 1, 2 *etc.*;
path difference between adjacent rays = $d\sin\theta = n\lambda$; ***[2]***

(b) $n = \left(\frac{d}{\lambda} =\right)\left(\frac{2.0\times10^{-6}}{5.2\times10^{-7}} =\right)3.85$;
so max = 3; ***[2]***

G4. (a)



two rays drawn showing scattering at equal angles from an atom in each layer;

statement to the effect that:
if the path difference between the scattered wave is equal to an integral number of wavelengths then the scattered waves will interfere constructively;
if the path difference between the scattered waves is equal to a half-integral number of wavelengths then the scattered waves will interfere destructively; ***[3]***

(b) $d = \dfrac{\lambda}{2\sin\theta}$;

$d = \left(\dfrac{8.7\times10^{-11}}{2.0\times0.31} = \right)140\,\text{pm}$ ***or*** $1.4\times10^{-10}\,\text{m}$; ***[2]***

G5. (a) light reflected from the top slide interferes with light reflected from the bottom slide; ***[1]***

(b) the light reflected from the bottom slide undergoes a π change in phase; ***[1]***

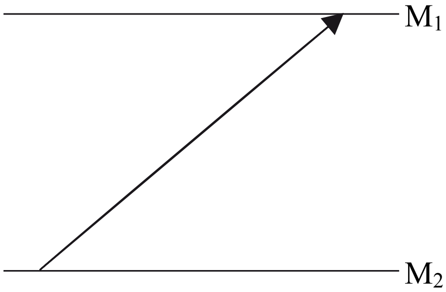
(c) in moving from one (bright) fringe to the next the thickness of the air film changes by $\dfrac{\lambda}{2}$;

in 5.0 cm number of fringes $= \dfrac{5}{0.940}\times 50 = 266$;

therefore diameter of hair $= 133\times5.92\times10^{-7} = 7.87\times10^{-5}\,\text{m}$;
$= 80\,\mu\text{m}$ ***[3]***

Option H — Relativity

H1. (a) any diagonal line as shown; *[1]*



(b) (i) $v\Delta t$; *[1]*

(ii) speed of pulse $\left(c^2+v^2\right)^{\frac{1}{2}}$;

distance $=\left(c^2+v^2\right)^{\frac{1}{2}}\Delta t$; *[2]*

(c) $c\Delta t$; *[1]*

(d) $d=c\Delta t'$;
from Pythagoras $d^2=c^2\Delta t'^2=c^2\Delta t^2-v^2\Delta t^2$;
$\Delta t=\dfrac{\Delta t'}{\sqrt{1-\dfrac{v^2}{c^2}}}$; *[3]*

(e) recognize that $2.3=\dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}}$;

some evidence of rearranging *e.g.* $v=\sqrt{\dfrac{[2.3]^2-1}{[2.3]^2}}$;

$=0.90\text{c}$ *[2]*

(f) $\left(\text{length}=\dfrac{1.8}{2.3}\right)=0.78\,\text{m}$; *[1]*

(g) *Look for these main points however expressed.*
muons produced in the upper atmosphere have speeds close to *c*;
many such muons are observed reaching the surface of Earth;
the half-life as measured in a muon's frame of reference does not give time for many to reach Earth / means many will have decayed in travelling to Earth;
but the contracted length of the journey/length as measured in a muon's reference frame means there is sufficient time;
and the dilated time/time measured by Earth observer is also sufficient for muons to reach the surface; *[5]*

H2. (a) momentum of photon $= 2.46\,\text{MeV}\,\text{c}^{-1}$;
momentum of electron–positron pair $= (2.46 - 0.880 =)\ 1.58\ \text{MeV}\,\text{c}^{-1}$;
$2p_{\text{electron}} \cos 45 = 1.58$;
$p_{\text{electron}} = \left(\dfrac{1.58}{2\cos 45} =\right)\ 1.12\,\text{MeV}\,\text{c}^{-1}$; ***[4]***

(b) total energy of electron $= \left(\sqrt{1.12^2 + 0.511^2} =\right)\ 1.23\,\text{MeV}$;
$\text{KE} = \text{eV}\left(= 1.23 - 0.511 = 0.72\,\text{MeV}\right) \rightarrow V = 0.72\,\text{MV}$; ***[2]***

H3. (a) no
it could be accelerating (upwards);
because of the principle of equivalence;
that states there is no way that gravitational effects can be distinguished from inertial effects; ***[3]***

(b) (i) the planet warps spacetime;
and the ball follows the shortest path in spacetime; ***[2]***

(ii) the black hole causes extreme curvature of spacetime;
any light leaving the surface will be bent back to the surface of the black hole / *OWTTE*; ***[2]***

(c) $8.8\,\text{mm}$ ***or*** $8.8 \times 10^{-3}\,\text{m}$; ***[1]***

Option I — Medical physics

I1. (a) (i) power per unit area; *[1]*

Do not accept answer based on formula given in (c).

(ii) the quantity $10\lg\frac{I}{10^{-12}}dB$, where I is the intensity of sound (and the reference intensity is $10^{-12}\ \mathrm{Wm}^{-2}$); *[1]*

(b) by the action of the ossicles;
by the difference in area between the oval window and the ear drum / the conical shape of the ear canal; *[2]*

(c) $\Delta IL = 10 = 10\lg\frac{I_2}{I_1}$;

$\frac{I_2}{I_1} = 10$;

$\frac{d_1^{\,2}}{d_2^{\,2}} = 10$;

$d_2 = \frac{25}{\sqrt{10}} = 7.9\,\mathrm{m}$; *[4]*

I2. (a) the distance after which the intensity of the incident X-rays gets reduced to half; *[1]*

(b) $\mu = \left(\frac{\ln 2}{x_{\frac{1}{2}}} = \frac{\ln 2}{3.50} = \right) 0.198\,\mathrm{mm}^{-1}$;

$\frac{I}{I_0} = \left(e^{-\mu x} = \right) e^{-1.98\times 6.00}$;

$\frac{I}{I_0} = 0.305$; *[3]*

or

X-rays travel $\frac{6}{3.5}(=1.71)$ half thicknesses;

$I = I_0\left[\frac{1}{2}\right]^{1.71}$;

$\frac{I}{I_0} = 0.350$;

(c) it will be larger;
because a larger half-value thickness implies a smaller attenuation coefficient and so a smaller reduction in intensity; ***[2]***

or

X-rays travel further before their energy is reduced by a given factor;
hence intensity is greater;

(d) (i) X-ray scattering (off the molecules of the medium); ***[1]***

(ii) to avoid scattered rays from reaching the film a grid of lead strips can be placed between the patient and the film;
and the grid is then moved back and forth in order to eliminate the images of the strips themselves; ***[2]***

(e) X-rays are incident on the intensifying screen after passing through the patient;
which then emits visible light that helps develop the photographic film; ***[2]***

I3. a laser transmits light across a thin part of a patient's anatomy (*e.g.* ear lobe/finger);
the amount of absorption by blood depends on the amount of oxygen in blood (bound to hemoglobin);
the absorbance of the light determines the amount of oxygen saturation; ***[3]***

I4. (a) absorbed dose is the energy absorbed per unit mass;
whereas the dose equivalent takes into effect the relative damage done by radiation / equals the absorbed dose times quality factor of radiation; ***[2]***

(b) (i) number of electrons emitted in 15 minutes is $\left(4.8\times10^{8}\times15\times60\right)=4.32\times10^{11}$;
energy of electrons is $\left(4.32\times10^{11}\times1.2\times10^{6}\times1.6\times10^{-19}\right)=0.0829\left(\text{J}\right)$;
absorbed dose is $\left(\frac{0.0829}{0.065}\right)=1.28\left(\text{Gy}\right)$;
and so dose equivalent is $1.28\times1=1.28\,\text{Sv}$; ***[4]***

(ii) the activity may not remain constant during the 15 minute interval;
not all radiation absorbed by the tumour; ***[1 max]***

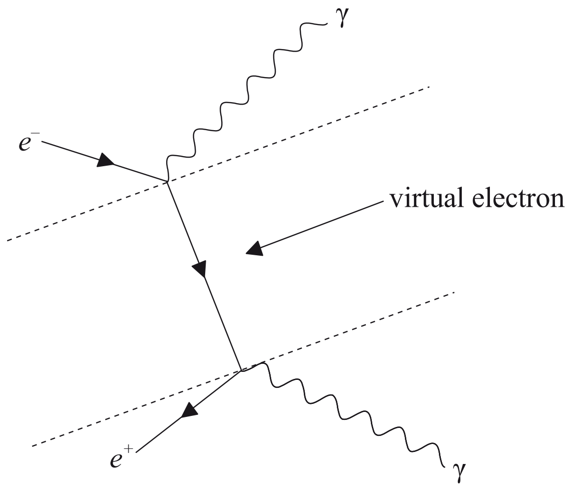
(iii) because the risk of the increased radiation might be less than the danger to the patient's health from an untreated tumour / *OWTTE*; ***[1]***

Option J — Particle physics

J1. (a) (i) a particle that cannot be made from any smaller constituents/particles; ***[1]***

(ii) has <u>the same rest mass</u> (and spin) as the lepton but opposite charge (and opposite lepton number); ***[1]***

(b)



*Award **[1]** for each correct section of the diagram.*
e^- correct direction and γ;
e^+ correct direction and γ;
virtual electron/positron; ***[3]***
Accept all three time orderings.

(c) (i) $u\bar{d}$ / up and anti-down; ***[1]***

(ii) baryon number is not conserved / quarks are not conserved; ***[1]***

(d) two identical particles that have half-integer spin/fermions cannot occupy the same quantum state; ***[1]***

(e) quarks are subject to the Pauli principle;
the introduction of colour ensures that the principle is not violated; ***[2]***

(f) $m_0 = \dfrac{h}{4\pi Rc}$;

$= \dfrac{6.6\times10^{-34}}{12.56\times10^{-15}\times3.0\times10^{8}} = 1.74\times10^{-28}\text{ kg}$;

$= \dfrac{1.74\times10^{-28}}{9.1\times10^{-31}}\times0.551 = 99\,\text{MeV c}^{-2}$; ***[3]***

Allow application of another appropriate conversion factor $\approx 100\,MeV\,c^{-2}$.

J2. (a) (i) into plane of paper; ***[1]***

(ii) spiral; ***[1]***
Ignore direction.

(iii) the period of a particle does not depend on the radius of its path;
the frequency of the ac supply must equal the revolution of the particle;
so that each time a particle passes across the gap between the D's the potential will be in such a direction as to accelerate the particle; ***[3]***

(b) radius of synchrotron greater;
in a cyclotron the maximum energy is determined by the size of the magnets/D's;
in a synchrotron particles move on fixed radius paths by adjusting the strength of the magnets;
the particles are accelerated by potential difference of increasing frequency/ in synchronization with the period of revolution of the particles; ***[3 max]***

(c) 1.1 GeV; ***[1]***

(d) $7\times 10^{12}\text{ eV} = \frac{3}{2}kT$;

$T = \frac{14\times 10^{12}\times 1.6\times 10^{-19}}{3.0\times 1.38\times 10^{-23}} \approx 10^{17}\text{ K}$;

so no; ***[3]***

or

Allow argument based on T for Big Bang.
e.g. T for Big Bang $= 10^{32}$ K;
Energy needed 2×10^{19} J;
$7\text{ TeV} = 10^{-6}$ J so no;

J3. (a) the theory that describes the electromagnetic and weak (and strong) interaction of quarks and electrons/particles; ***[1]***

(b) ν_{μ} / muon neutrino; ***[1]***

(c) scattering (of leptons by hadrons) in which large amounts of energy is transferred (to the hadrons); ***[1]***

(d) asymptotic freedom means particles behave as free particles at high energies;
in DISE large amounts of energy are transferred making quarks (in hadrons) behave as free particles; ***[2]***