N13/4/PHYSI/HP3/ENG/TZ0/XX/M

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MARKSCHEME

November 2013

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 <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 ***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) realizes that motion of Canis Minor is due to Earth's rotation (relative to stars);
specific reference to west to east rotation of Earth and relative opposite rotation of Canis Minor; ***[2]***
If second marking point is awarded then award first marking point also.

(b) apparent magnitude / brightness of a star;
at a distance of 10 pc (from observer); ***[2]***

or

a logarithmic measure/scale;
of the star's luminosity;

(c) (i) apparent magnitude is smaller than/similar to absolute magnitude;
so Luyten's star must be closer than 10 (pc) / must be relatively close to Earth;
this is less than 100 (pc); } *(allow values in the range of 10 (pc) to 1000 (pc) for upper limit)* ***[3]***

or

$$9.9-11.9=5\lg\left(\frac{d}{10}\right);$$

so $d=4.0$ (pc);
this is less than 100 (pc); *(allow values in the range of 10 (pc) to 1000 (pc))*
Allow ***[2 max]*** *ECF if magnitudes are reversed giving 25 (pc).*
Allow third marking point (ECF) after incorrect value for d only if value is less than 1000 (pc).
Do not award the third marking point for vague statements that the distance is within parallax range.

(ii) *Allow a very wide range of upper limits*:
up to X; *(where 10 kpc < X < 10 Mpc)* ***[1]***
Ignore any lower limit.

(d) (i) $2.9 = -0.7 + 5\lg\left(\frac{d}{10}\right)$;

$\frac{d}{10} = 10^{\frac{3.6}{5}}$;

52 (pc); **[3]**

*Award **[2 max]** ECF if magnitudes are reversed giving 1.9 (pc).*
*Award **[2 max]** if data for Lutyen's star is used and no credit for the distance of 4 (pc) has already been given in (c)(i).*
*Award **[3]** for a bald correct answer.*

(ii) $\frac{L_G}{L_S} = \left[\frac{R_G}{R_S}\right]^2 \left[\frac{T_G}{T_S}\right]^4$;

$= 4^2 \times \left[\frac{11000}{5800}\right]^4$;

$= 210$; *(must see this answer to better than 1 significant figure)* **[3]**

Approximate answer of 200 is given in the question so correct steps in the working are required to award any marks.

(iii) $\frac{m_G}{m_S} = \left[\frac{L_G}{L_S}\right]^{\frac{1}{3.5}}$ / *OWTTE*;

allow values in the range of 4.3 to 4.6; **[2]**

Allow ECF from (d)(ii).
*Award **[2]** for a bald correct answer.*

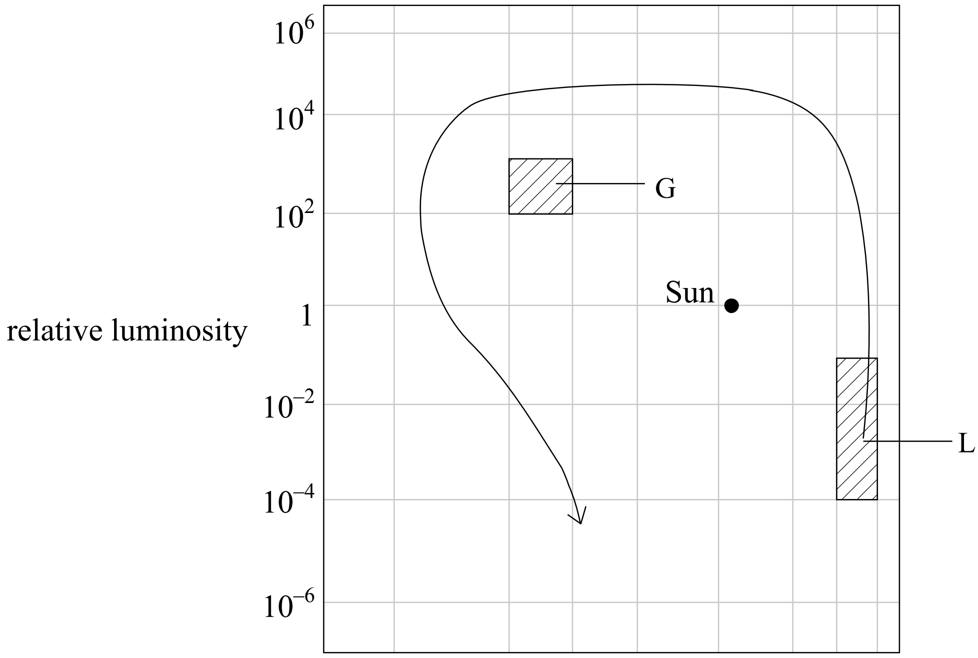
(iv) mentions value of (Chandrasekhar limit) 1.4 solar masses;

if (remnant) mass of G is greater than the Chandrasekhar limit, it would become a neutron star; *(ignore any reference to a black hole)*

if (remnant) mass of G is less than the Chandrasekhar limit, it would become a white dwarf; **[2 max]**

Do not award both second and third marking points.
Award second or third marking point for the general idea, consistent with any value used for Chandrasekhar limit.
Allow ECF from (d)(iii).
For masses of G, from (d)(iii), which are over 8 solar masses, allow reference to a black hole as eventual fate.

(e)



(i) G correct within region shown; *[1]*

(ii) L correct within region shown; *[1]*

(f) any anticlockwise path that goes above and right of the Sun and passes through/ends below and left of the Sun; *[1]*

2. (a) uniform / homogeneous / isotropic;

has existed forever/infinite age; } *(must refer to "time", as infinite (space) is given in the question)* ***[1 max]***

(b) the light from (distant) galaxies is red-shifted;
this shows that they are moving away from us/each other;
so the universe is expanding/changing; ***[3]***

or

CBR is red-shifted (remnant of the Big Bang);
CBR was originally very short wavelength/very high frequency/very high temperature;
its current longer wavelength/low temperature is evidence that the universe has expanded;

Allow reverse arguments eg. universe expansion so galaxies moving apart so red-shift.

3. (a) (i) straight line that passes through the origin (or would do so if extrapolated); ***[1]***

(ii) gradient is H_0 / Hubble's constant;

age of universe is $\dfrac{1}{H_0}$ ***or*** age is $\dfrac{1}{\text{gradient}}$; ***[2]***

(b) $v = (0.18 \times c =) 5.4 \times 10^7\ (\text{m s}^{-1})$ ***or*** $5.4 \times 10^4\ (\text{km s}^{-1})$;

$d = \dfrac{v}{70} = 770\ (\text{Mpc})$ ***or*** $2.4 \times 10^{25}\ (\text{m})$; ***[2]***

Award ***[1 max]*** *if v is correctly calculated but left in m s^{-1}, giving an answer of 770 000 (Mpc).*
Award ***[1 max]*** *ECF for an incorrect value of v used correctly in km s^{-1}.*
Award ***[0]*** *for an incorrect value of v and failure to convert to km s^{-1}.*
Award ***[2]*** *for a bald correct answer.*

Option F — Communications

4. (a) carrier wave is changed by a signal wave;
to allow the carrier to transfer information; ***[2]***

(b) (i) amplitude is constant; ***[1]***

(ii) frequency changes by $\pm 1.5 \times 12$ (kHz) (18 kHz);
so from 93.982 (MHz) to 94.018 (MHz);
6000 times every second; ***[3]***
If second marking point is awarded, award first marking point also, even if it is not explicit.

(c) $(2 \times 18) = 36\,(\text{kHz})$; ***[1]***

or

$(2 \times [18 + 6]) = 48\,(\text{kHz})$;
Allow ECF from (b)(ii).

5. (a) (i) dispersion occurs;
resulting in signals/light taking different times to travel along the fibre;
(modal dispersion) is dependent on path taken/internal reflections;
(material dispersion) depends on variation of wave speed with wavelength; ***[3 max]***

(ii) area of pulse indicates energy in pulse;
smaller, so energy less; ***[2]***
*Award **[1 max]** for discussion of height of pulse.*

(b) reference to time gaps/dead time between pulses in signal transmission;
(time-division multiplexing) merges many separate signals to fill these gaps;
(this is cost-effective since) the rate of information/data transfer rate along a fibre increases / fewer fibres needed; ***[3]***

(c) (i) wire pair / coaxial cable / radio waves; ***[1]***

(ii) lower cost;
less time delay;
easier to maintain;
less attenuation; (*this is uncertain but allow*) ***[1 max]***
Allow other reasonable responses.

(iii) less power required each way;
less expensive to put into orbit;
less time delay on message round trip;
can cover whole surface over several orbits rather than continuous over smaller area; ***[2 max]***
Do not reward a response of "different heights" without consideration of the above marking points.

6. (a) switching/re-shaping (digital pulses);
square wave/function generator;
noise suppression; ***[1 max]***

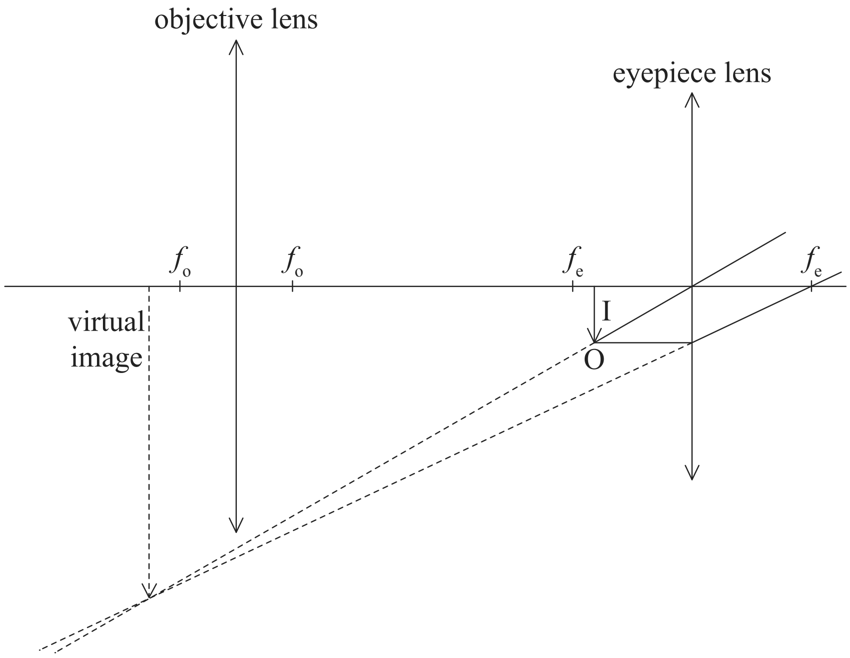
(b) *Look for these main ideas*:
V_{OUT} is either +15 (V) or –15 (V) / *OWTTE*;
V_{x} is $\pm 15\,\text{V}\times\frac{R_1}{(R_1+R_2)}$ ***or*** $V_{\text{OUT}}\times\frac{R_1}{(R_1+R_2)}$;
when V_{IN} becomes $>+V_{\text{x}}$, V_{OUT} switches to $-15\,(\text{V})$;
when V_{IN} becomes $<-V_{\text{x}}$, V_{OUT} switches to $+15\,(\text{V})$; ***[4]***
Accept similar arguments which refer to V_{supply} *instead of 15 (V).*
Accept answers which use values for V_{x} *(±1.5 (V)) in second, third and fourth marking points.*
Allow third and fourth marking points even if the polarities are the other way round.

(c) use of $\left[\frac{R_1}{R_1+R_2}\right]$ ***or*** gain $=1+\frac{R_2}{R_1}$;
(magnitude of) $V_{\text{X}}=1.5\,(\text{V})$;
switches at $\pm 1.5\,(\text{V})$; ***[3]***
Allow ECF from second to third marking point.

7. cellular exchange monitors signal strength;
between phone and base stations;
cellular exchange switches between base stations;
to maintain maximum signal strength; ***[3 max]***

Option G — Electromagnetic waves

8. (a)



at least two rays from O correctly refracted at eyepiece;
completed extrapolation of these rays to form a virtual image; ***[2]***

Ignore rays refracted by the objective lens.
*Award **[1 max]** ECF in second marking point.*
Allow virtual image positions to be either side of objective lens.
*Award **[0]** for formation of a real image.*

(b) (i) $u = (18.1 - 14.8 =) 3.3$ (cm);

$\frac{1}{v} = \frac{1}{3.8} - \frac{1}{3.3}$;

(–)25.1 (cm); ***[3]***

*Award **[2 max]** ECF for wrong u value (eg. 14.8 (cm) giving an answer of v = 5.1 (cm).*
*Award **[1 max]** if positive sign appears in second term in right-hand side of equation.*
*Award **[3]** for a bald correct answer.*

(ii) $M_{\text{eye}} = \left(\frac{D}{f} + 1 = \frac{25.1}{3.8} + 1 = \frac{25.1}{3.3} = \right) 7.6$;

overall magnification $= (6 \times 7.6 =) 46$; ***[2]***

*Award **[2]** ECF from (b)(i).*
*Award **[1 max]** ECF from first to second marking point.*
*Award **[2]** for a bald correct answer.*

(c) each colour/wavelength has a different refractive index / *OWTTE*;
a range of wavelengths focuses different colours/wavelengths at different points/distances;
reducing the range of wavelengths reduces the range of image distances/reduces the coloured edging to images/reduces dispersion; ***[2 max]***

9. (a) net displacement of the medium;
equals the resultant/sum of individual displacements; ***[2]***
*Award **[1 max]** for reference to amplitude rather than displacement.*
*Award **[0]** for reference only to troughs and crests.*

(b) (i) interference/superposition occurs at A;
between waves from each opening;
waves arrive in phase / path difference is one wavelength;
producing a (1st order) maximum; ***[3 max]***
*Award **[3 max]** for clear points that appear on diagram.*

(ii) maxima occur when the path difference is an integral number of wavelengths;
because wavelength doubles, larger distances/angles required to achieve same path difference;
successive maxima fringes are twice as far/further apart; ***[3]***

or

quotes double slit/grating formula;
substitute 2λ into equation and states all other terms stay constant;
successive maxima fringes are twice as far/further apart;

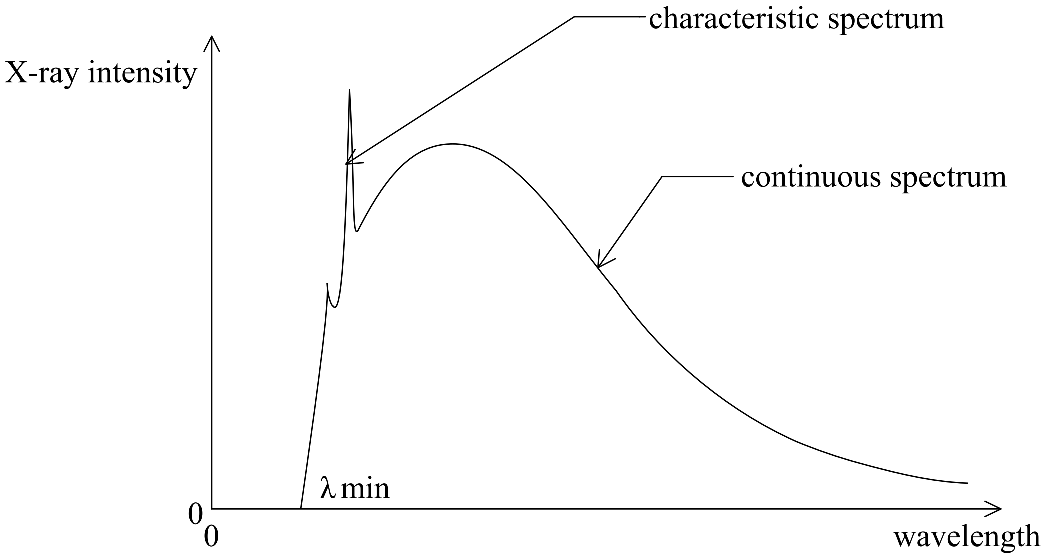
(c) *Assuming spacing of openings stays the same.*
same separation of maxima;
maxima increase in amplitude/intensity;
maxima narrower/sharper;
formation of secondary maxima; ***[2 max]***
*Award **[2 max]** for other reasonable responses if the response clearly states an assumption that the openings are closer or further apart than before.*

10. (a) (i) $\dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{1.6\times10^{-19}\times50\,000}$;

2.5×10^{-11} (m); ***[2]***

*Award **[1 max]** ECF if 50 (V) used to give 2.5×10^{-8} (m).*
*Award **[2]** for a bald correct answer.*

(ii)



overall shape approximately correct with non-zero cut-off and at least one relevant annotation such as those shown above;
characteristic spectrum positive spike(s) of any shape, wavelength or intensity; ***[2]***

Do not award first marking point for curves which touch the x-axis at long wavelength unless "asymptotic".

(b) *Look for these main points*:
electrons give energy to electrons in the innermost orbit/lowest energy levels;
these electrons ejected from the atom; *(do not accept excitation of electrons)*
energy levels filled by electrons form higher energy levels; } *(allow de-excitation as ECF)*
emitting X-rays/photons with energy equal to the difference in electron energy levels;
these photons have the characteristic spectra wavelength; ***[3 max]***

11. (a) there are $\frac{60}{0.29}$ fringes $= 207$;

$2 \times 1 \times t = 207 \times 5.9 \times 10^{-7}$;

$t = 61\,(\mu\text{m})$; ***[3]***

or

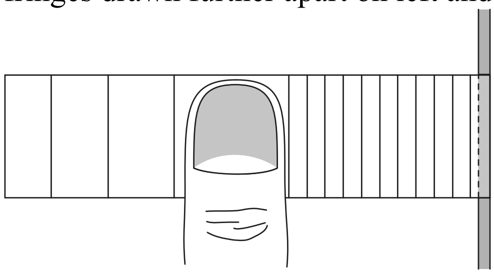
$(\tan\theta =)\dfrac{t}{6.0\,(\text{cm})} = \dfrac{0.5\lambda}{\Delta x}$;

$t = \dfrac{[0.06\,(\text{m}) \times 0.5 \times 5.9 \times 10^{-7}\,(\text{m})]}{0.00029\,(\text{m})}$;

$t = 61\,(\mu\text{m})$;

A phase change of $\frac{1}{2}\lambda$, if seen in working, can be ignored and does not affect the answer.
*Award **[3]** for a bald correct answer.*

(b) fringes drawn further apart on left and closer on right; ***[1]***



Do not penalize any uneven spacing or curvature as long as above idea is clear.
(Memorize left to right spacing here as "BIG-small").

Option H — Relativity

12. (a) a set of coordinates that can be used to locate events/position of objects; ***[1]***

(b) (i) $\dfrac{1.80\times10^{11}}{0.750\times3\times10^{8}}$;
$=800\,(\text{s})$; ***[2]***
*Award **[2]** for a bald correct answer.*

(ii) $\gamma=\left(\dfrac{1}{\sqrt{1-0.750^2}}=\right)1.51$;
$\text{time}=\left(\dfrac{800}{1.51}=\right)530\,(\text{s})$; ***[2]***
Watch for ECF from (b)(i) or first marking point in (b)(ii).
*Award **[2]** for a bald correct answer.*

(iii) only S’s clock measures proper time;
because S’s clock is at both events / events occur at same place in S’s frame; ***[2]***

(iv) according to S, Y moves towards/X moves away from the radio signal;
the signal travels at the same speed/at the speed of light in each direction;
therefore according to S’s clock the signal reaches Y before it reaches X/X after reaching Y; ***[3]***

or

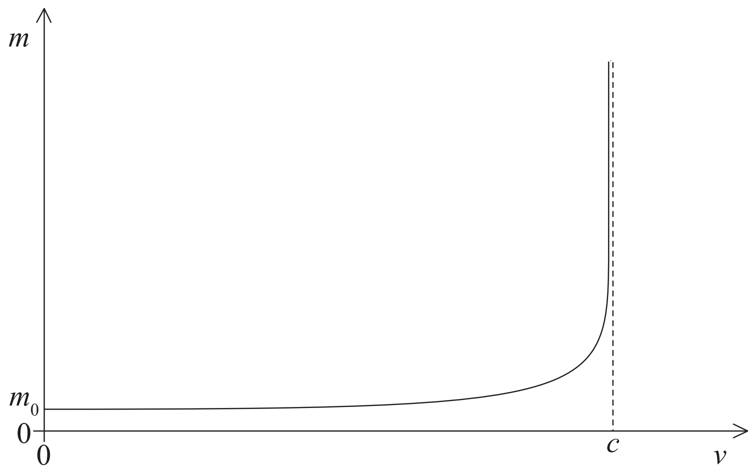
S’s frame is different/moving relative to the X and Y frame;
the two events/arrival of signals are separated in space;
so if simultaneous for XY, cannot be simultaneous for S;

(c) (i) rest mass $= \dfrac{\text{total energy}}{\gamma c^2}$; *(allow ECF for γ from 12(b)(ii))*

$= \left(\dfrac{2.72\times10^{20}}{1.51\times9\times10^{16}}=\right)2.0\times10^{3}\,(\text{kg})$; **[2]**

*Award **[1 max]** if gamma is not used and answer is 3000 (kg).*
*Award **[2]** for a bald correct answer.*

(ii)



general shape showing asymptote to $v = c$;
non-zero value for $m = m_0$; **[2]**

(d) the muons are equivalent to S and the Earth to X,Y;
without time dilation most muons would decay before reaching the Earth's surface;
from Earth frame, with time dilation, the (proper) half-life of muons becomes dilated/larger;
from muon frame, with time dilation, the (proper) journey time is less than that on Earth; *(do not award marking point for arguments just based on length contraction)*
fewer muons decay/more muons survive than expected without time dilation; *(award marking point even if no explanation is given)* **[3 max]**

13. (a) $V = [\gamma - 1]\, 938 \times 10^6$;
$\gamma = 4$;
$V = \left(3 \times 938 \times 10^6 =\right) 2.81 \times 10^9$ (V) ***or*** 2.81 (GV); ***[3]***

or

$\mathrm{eV} = [\gamma - 1]\, \mathrm{mc}^2$;
$\gamma = 4$;
$V = \left(\dfrac{3 \times 1.67 \times 10^{-27} \times 9 \times 10^{16}}{1.6 \times 10^{-19}}\right) = 2.81 \times 10^9\,(\mathrm{V})$;
*Award **[3]** for a bald correct answer.*

(b) (i) recognize that $4 = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}$;
to give $v = 0.968\mathrm{c}$ ***or*** $2.90 \times 10^8\,(\mathrm{ms}^{-1})$; ***[2]***
*Allow **[2 max]** ECF for wrong γ taken from (a).*
*Award **[2]** for a bald correct answer.*

(ii) $p = \left(\gamma m_0 v =\right) 1.9 \times 10^{-18}\,(\mathrm{kg\,ms^{-1}})$ ***or*** $3.63 \times 10^3\,(\mathrm{MeV\,c^{-1}})$ ***or*** $3.63\,(\mathrm{GeV\,c^{-1}})$; ***[1]***
Watch for ECF from (a) or (b)(i).

14. (a) spacetime is a (4 dimensional) coordinate system/a coordinate system used to locate events;
consisting of three space coordinates and one time coordinate; ***[2]***

(b) (i) the mass of the Sun causes the spacetime around it to be warped;
objects follow the shortest path/geodesic between points in spacetime;
for the Earth this an elliptical/circular path about the Sun; ***[3]***

(ii) black holes produce a region of spacetime with extreme curvature; *(must indicate the curvature is very large for this mark)*
such that not even radiation can escape from the influence of a black hole; ***[2]***

Option I — Medical physics

15. (a) $10\lg_{10}\left[\frac{I}{I_0}\right]$ where $I_0 = 1\times10^{-12}$ (W m^{-2}) ***or*** threshold intensity; ***[1]***

(b) (i) reduced sensitivity / reduced frequency range;
occurs with age;
(hence B) ***[2]***
*Award **[0]** for a bald correct answer.*

(ii) reads intensity level difference as 15 dB;
$15 = 10\lg_{10}\left[\frac{I_G}{I_C}\right]$;
$\frac{I_G}{I_C} = 32$;
$d = \frac{30}{\sqrt{32}} = 5.3$ (m); ***[4]***
*Allow **[3 max]** for an inverted ratio giving 170 (m).*
Expect alternative approaches for working where I is calculated for G (3.16×10^{-11}) and C (1×10^{-12}).
*Award **[4]** for a bald correct answer.*

16. (a) μ in $I = I_0 e^{-\mu x}$;
all symbols defined; ***[2]***

or

the probability per unit length/metre;
of a photon being absorbed;

(b) (i) $I_A = I_0 e^{[-\mu_e 2x - \mu_f y]}$ ***or*** $I_B = I_0 e^{[-\mu_e 2x - \mu_t y]}$;

$\frac{I_A}{I_B} = \frac{e^{[-\mu_e 2x - \mu_f y]}}{e^{[-\mu_e 2x - \mu_t y]}}$;

$= e^{[-[6.3 - 0.3]2.5]}$;

$= 3.1 \times 10^{-7}$; ***[4]***

Do not apply a marking penalty if attenuation effect of enamel is ignored, as it is the same for both rays.
Award first and second marking point by implication if only the correct working of the third marking point is shown.
Approximate answer is given in the question, so look for working and at least two significant figures in the final answer (3.059...).

(ii) intensity ratio is very small / intensity for A is much less than at B;
so if the contrast is correct for B, it cannot be correct for A / A will be underexposed so contrast will be poor; ***[2]***

or

compared to B, the much smaller intensity for A is due to the filling;
for A, small changes in enamel attenuation coefficient will be insignificant compared to that of the filling, so contrast is poor;

(c) quicker procedure;
less dose overall / safer; ***[2]***

(d) acoustic impedance difference between decayed and good tissue is very small so reflection will be weak;
the acoustic impedance of tissue/decayed tissue is much smaller than for enamel so contrast would be poor;
difficult to get ultrasound signal into tooth given mismatch between acoustic impedance of air and enamel;
there will be a strong internal reflection when reflection from tissue is incident on enamel from inside; ***[2 max]***

17. two lights/lasers (red and infrared) shine through finger/ear/tissue;
absorption of each light depends on oxygen levels in hemoglobin/blood / *OWTTE*;
ratio/comparison of absorptions determines percentage of oxygen; ***[3]***

18. (a) (i) *Accept answers such as*:
physical/radioactive decay of Bismuth is far more rapid than the biological elimination;
five days is about 150 times the physical half-life, so activity will be minimal long before time to excrete;
the effective half-life is almost equal to physical half-life, so biological half-life is unimportant; ***[1 max]***

(ii) reference to greater quality factor/RBE for alpha / *OWTTE*;
alpha particles have short range so concentrates effect on tumour;
short effective half-life so disappears quickly/no long-term risk;
as beta is low energy likely to be absorbed by tumour mass too;
little risk to anyone in contact with patient; ***[2 max]***

(b) (i) *Exact method*:

$N_0 - N = \dfrac{(A_0 - A)}{\lambda}$;

$= \dfrac{3.6\times10^{8}\times(45\times60)}{\ln 2} = 1.4\times10^{12}$; ***[2]***

or

Approximate method:
45 minutes is one half-life so assume that average activity is about 5.4×10^{8} (Bq);
$45\times60\times5.4\times10^{8} = 1.5\times10^{12}$;
*Also award **[2]** if only final or original activity is used to give values 0.97×10^{12} or 1.94×10^{12}.*
Approximate answer is given in the question, so credit correct working only.

(ii) energy $= \left(1.4\times10^{12}\times6\times10^{6}\times1.6\times10^{-19} =\right) 1.34$ (J); *(allow answers in the range of 0.96 (J) to 1.86 (J))*

absorbed dose $= \dfrac{1.34}{0.045} = 30$ (Gy); *(allow answers in the range of 20 (Gy) to 42 (Gy))*

dose equivalent $= 30\times10 = 300$ (Sv); *(allow answers in the range of 200 (Sv) to 420 (Sv))* ***[3]***

*Award **[3 max]** for similar working using the answer to (b)(i) giving values in the ranges stated.*
Allow ECF for second and third marking points if correct division by 0.045 and multiplication by 10 are obvious from the working, even if the energy value is incorrect.

Option J — Particle physics

19. (a) (i) W^-; *(allow W^+, W boson)* ***[1]***

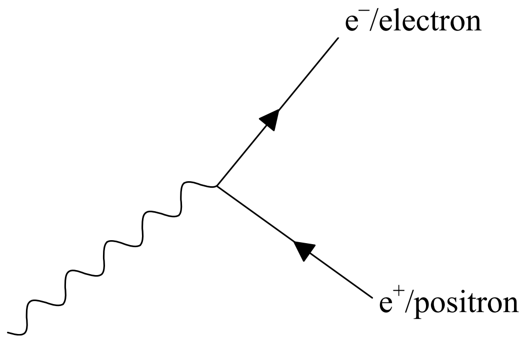
(ii) proton; ***[1]***

(iii) π^0 is a (neutral) meson;
π^0 has integer spin/is a boson;
π^0 is unstable;
π^0 is its own antiparticle; ***[2 max]***

(b) $m = \frac{h}{R4\pi c}$; *(must see evidence of rearrangement to award this mark)*
82 (MeV c^{-2}); *(do not accept answers in kg)* ***[2]***
*Award **[2]** for a bald correct answer.*

(c) (i) pair production; ***[1]***

(ii)



single vertex showing photon and two correctly labelled particles;
arrow direction correct for e^+ and e^-; ***[2]***
Allow time axis to run vertically.
If Feynman diagrams include the meson decay, only consider either gamma's pair production.

(d) (i) strangeness is not conserved, changes from –1 to 0;
weak interaction does not have to conserve strangeness in decay of Σ^+; ***[1 max]***

(ii) strangeness is 0 before and after, so is conserved;
γ decays by the electromagnetic interaction and strangeness conserved; ***[1 max]***
To award the marks reasoned answers are required in (d)(i) and (d)(ii).

20. (a) (i) E field accelerates/increases speed/energy of particles (in cavity);
B field accelerates towards the centre of ring/deflects particles into circular path/maintains constant orbital radius; ***[2]***

(ii) E field is alternating/reverses while particle is in the cavity;
E field frequency has to increase to match increase in particle speed;
magnetic field has to increase to match increase in speed;
magnetic field has to increase to match increase in mass/energy; ***[4]***

(b) use of $v = c$ and $m = \frac{E}{c^2}$ giving $B = \frac{E}{qcr}$;

$$= \frac{400\times10^{9}\times1.6\times10^{-19}}{1.6\times10^{-19}\times3\times10^{8}\times\left[\frac{27\times10^{3}}{2\pi}\right]};$$

0.31 (T); ***[3]***

or

$$\text{proton mass} = \left(\frac{400\,(\text{GeV})}{938\,(\text{MeV})}\times1.67\times10^{-27} = \right)7.1\times10^{-25}\ (\text{kg})\ ;$$

$$B = \frac{7.1\times10^{-25}\times3\times10^{8}\times2\pi}{1.6\times10^{-19}\times27\,000};$$

0.31 (T);
*Award **[1 max]** for a simple substitution of proton rest mass into the equation giving an answer of 0.00073 (T).*
*Award **[3]** for a bald correct answer.*

(c) high costs can be shared by nations;
requires talented/expert/large teams of scientists and engineers so drawn from many countries; ***[2]***
Accept similar valid responses.

21. *The question refers to high energy protons so accept the following*:
by experiments such as deep inelastic scattering;

where high energy leptons/electrons/protons collide with protons; *(the question refers to high energy protons, so allow protons as well as leptons or electrons)*

the scattering data show that protons are composed of quarks/more elementary particles;
at high energies quarks display asymptotic freedom;
free quarks are not observed – showers of mesons/baryons/hadrons are;
this is called quark confinement / this is known as hadronization; ***[4 max]***

or

*The question refers to high energy protons, which may elicit responses which refer to, for example, LHC proton-proton scattering or collisions. This is not on the syllabus, but award up to **[3 max]** to responses including any correct Physics.*

eg.:
mention of two beams of high energy protons colliding;
in a particle accelerator such as LHC;
mention of re-creation of conditions in the early hot universe;
mention of quark - gluon plasma;
mention of discovery of W/Z/Higgs boson;

22. (a) nucleosynthesis is the production of nuclei/elements from (more fundamental) particles by fusion; ***[1]***

(b) in the very early universe the temperature/particle energy was too high for nucleons to be stable/exist/fuse;
during the 17 minutes the temperature/energy range was suitable for maintaining fusion;
after this time the temperature/energy was too low for fusion; ***[3]***
*To award **[3]** responses must refer to temperature or (particle) energy.*