N14/4/PHYSI/HP3/ENG/TZ0/XX/M

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MARKSCHEME

November 2014

PHYSICS

Higher Level

Paper 3

18 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) stars of stellar cluster are close together (in space)/bounded gravitationally;
stars of constellations are not bounded gravitationally/appear to be close together (from Earth); ***[2]***

(b) the stars rise in the east/northeast/southeast and set in the west/northwest/southwest (moving in an arc across the sky) / a description of arcs (as if rotating) in clockwise/anticlockwise direction / *OWTTE*; ***[1]***
An answer such as "move like Sun" is not sufficient for the mark.
Accept answers based in either hemisphere.

2. (a) (i) Alnilam must be further away from Earth than Bellatrix;
Alnilam has greater luminosity with a more negative absolute magnitude / absolute magnitude is a measure of how bright the star is if it is positioned 10 pc away from Earth (and apparent magnitude is a measure of how bright the star is from Earth) / *OWTTE*; ***[2]***

(ii) $\frac{L_A}{L_B} = \frac{275000}{6400}$ ***or*** $\frac{L_A}{L_B} = \frac{\sigma A_A T_A^4}{\sigma A_B T_B^4}\left(= \frac{4\pi R_A^2 T_A^4}{4\pi R_B^2 T_B^4} = \frac{R_A^2 T_A^4}{R_B^2 T_B^4} = \frac{275000}{6400}\right)$;

$\frac{[24R_o]^2}{[6R_o]^2} \times \frac{27000^4}{T_B^4} (= 42.96)$;

$T_B = \left(\sqrt[4]{\frac{24^2}{6^2} \times \frac{27000^4}{42.96}} = \right) 21100\,\text{K}$; ***[3]***

(b) (i) the position of the star (relative to the fixed background) is measured six months apart/January to July;

the parallax angle *p* can be used to determine the distance using $d = \frac{1}{p}$; ***[2]***

(ii) $\left(m - M = 5\log\frac{d}{10}\right)$

$d = 10 \times 10^{\frac{m-M}{5}} = 10 \times 10^{\frac{1.68-(-6.37)}{5}}$;
$= 407$ (pc);
the distance of Alnilam cannot be determined (from Earth) using stellar parallax as it is further than 100 pc / the distance to Alnilam could be determined by parallax due to recent improvements (in astrophysics); ***[3]***
Do not accept value less than 100 pc, accept any value from 100 pc to 1000 pc.

3. (a) (an infinite) universe can be split into an infinite number of thin shells with diameter of r (with Earth in the centre);
the number of stars in each shell is proportional to r^2 and the brightness of each star is inversely proportion to r^2;
this means that each shell is equally bright (as seen from Earth); ***[3]***

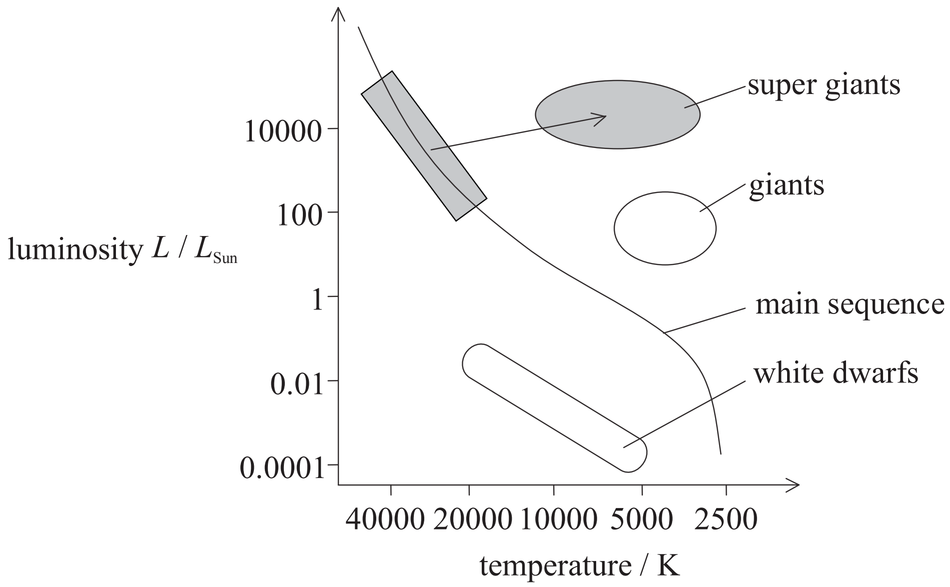
(b) the temperature has cooled considerably since the Big Bang / the Big Bang model predicted cooling and the present temperature;
this cooling was caused by the expansion of the universe/the stretching of spacetime; ***[2]***

(c) the Big Bang suggests that the universe had a starting point in time;
light from distant stars has been red-shifted beyond the visible spectrum;
light from distant stars has not yet reached us;
the universe has a finite number of stars; ***[2 max]***

4. (a) $\frac{L}{L_{\odot}} = \left(\left[\frac{m}{m_{\odot}}\right]^{3.5} = \right)\left[\frac{18m_{\odot}}{m_{\odot}}\right]^{3.5}$;
$L = 25000\ L_{\odot}$; ***[2]***
Answer must include $L_{\odot}$ *in correct place.*

(b) Phi-1 Orionis has a larger mass so it has a larger <u>gravitational pressure</u>;
to remain in equilibrium it requires (an equal) radiation pressure which is provided by burning (hydrogen) at a faster rate; ***[2]***

(c) (i) line drawn starting from the top-left of the main sequence towards (red) super giants; } *(allow anywhere within the grey shaded regions)* ***[1]***



(ii) (mass of star is more than 15 solar masses so can be predicted, that) after supernova explosion it will be more than 3 solar masses/Oppenheimer-Volkoff limit and become a black hole; ***[1]***

or

if the mass after supernova explosion will be less than then Oppenheimer-Volkoff limit, it will become a neutron star;

5. (a) $T = \frac{1}{H}\left(= \frac{1}{70\,\text{km s}^{-1}\,\text{Mpc}^{-1}}\right)$;

$T = \left(\frac{1}{70\ 000\,\text{s}^{-1}} \times 10^{6} \times 9.46 \times 10^{15} \times 3.26 =\right) 4.4 \times 10^{17}\,\text{s}$; ***[2]***

(b) $\left(\frac{\Delta\lambda}{\lambda} = \frac{v}{c}\right)$

$\frac{\Delta\lambda}{\lambda} = \frac{725.6 - 656.3}{656.3} = 0.106$;

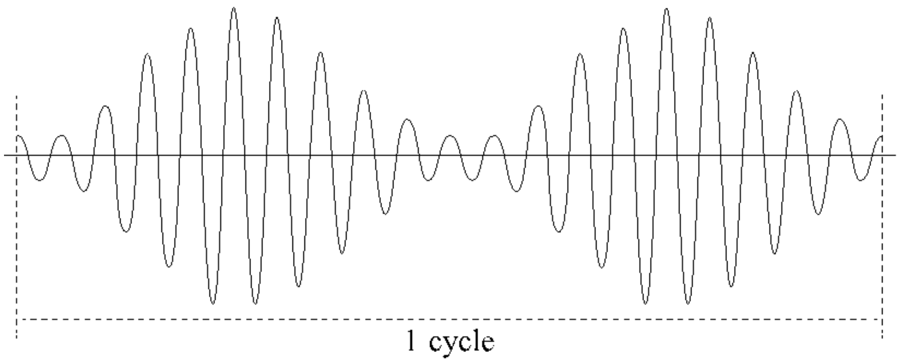
$v = \left(\frac{\Delta\lambda}{\lambda} \times c = 0.106 \times 3 \times 10^{8} =\right) 3.17 \times 10^{7}\,\text{m s}^{-1}$; ***[2]***

Option F — Communications

6. (a) (i) AM: the amplitude of the carrier wave is changed when modulated by the signal wave / *OWTTE*;
FM: the frequency of the carrier wave is changed when modulated by the signal wave is / *OWTTE*; ***[2]***

(ii) for information to be carried by a wave; ***[1]***

(iii) carrier frequency consistent and at least one cycle of carrier wave shown;
amplitude of carrier frequency to fit within the envelope of the audio signal; ***[2]***



(b) *advantage*: ***[1 max]***
simpler circuitry;
narrow bandwidth;
large range;

disadvantage: ***[1 max]***
more susceptible to noise;
poorer quality signal;
noise cannot be reduced; ***[2 max]***
Do not allow "expensive".

7. (a) (4 samples every 2 ms/any other correct combinations of points) = 2000 Hz; ***[1]***

(b) 1011; ***[1]***

(c) increase the sampling rate;
more samples taken per unit time so the digital output is smoother / *OWTTE*; ***[2]***

or

increase the number of bits;
smaller changes between each quantum level in the digital signal so the output is smoother / *OWTTE*;

8. (a) (i) $\left(\sin C = \frac{1}{n} = \frac{1}{1.62} \Rightarrow C = \right) 38(.1)^{\circ}$ ***or*** 0.665 rad; ***[1]***

(ii) rays with an angle of greater than 38° shown with total internal reflection;
normal drawn onto diagram for at least one point;
pairs of angles of incidence and reflection the same; ***[2 max]***
Judge by eye.

(b) $\text{attenuation/dB} = \left(10\log\frac{I_1}{I_2} = \right)10\log\frac{3\,\text{mW}}{150\,\text{mW}}$ ***or*** $-17.0\,\text{dB}$;

$\text{length} = \left(\frac{\text{attenuation}}{\text{attenuation per unit length}} = \frac{-17.0}{12} = \right)1.42\,\text{km}$; ***[2]***

(c) (i) the width of the output signal is wider than that of the input signal;
due to material dispersion / different frequencies travel at different speeds; ***[2]***
Do not accept "reduced power".

(ii) reshapers reduce the spread of the output signal;
amplifiers increase the power of the signal; ***[2]***

9. (a) satellite that orbits with a period of 24 hours/same period of rotation as Earth;
remaining above the same position on the Earth's surface; ***[2]***

(b) *advantage*: ***[1 max]***
Polar orbiting satellite has:
lower orbit height so stronger signal received/less power required;
lower orbit height so cheaper/less energy required to get into orbit;
most of Earth's surface receives coverage at regular intervals;
orbit is closer to Earth so more detail/better resolution can be obtained;

disadvantage: ***[1 max]***
Polar orbiting satellite has:
no fixed position so tracking is required;
unable to maintain permanent link with satellite from one point on the Earth;
close orbit so smaller area covered at any one time; ***[2 max]***

(c) the transmitter will affect the receiver if on the same frequency;
the different frequencies prevent resonance occurring between transmitting and receiving devices;
the lower frequency for the down-link allows for it to be transmitted more energy-efficiently from the satellite;
different frequencies mean that the high power signal being transmitted from Earth does not drown out the weak signal received from the satellite; ***[1 max]***

10. (a) as temperature decreases, potential difference across the thermistor increases;
voltage at the inverting input of the op-amp decreases; ***[2]***

(b) to control/to set the temperature at which some action/signal is given; ***[1]***
Allow logical, specified actions such as turning on heaters, closing vents.

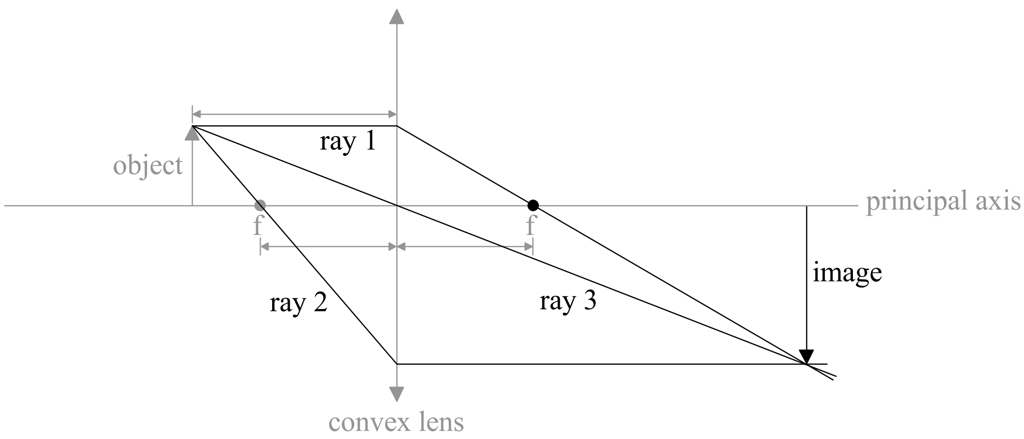
(c) potential difference across the thermistor $= \left(30 \times \frac{193}{193+300} = \right) 11.74\,\text{V}$;

the voltage at the inverting input of the op-amp will be $15\,\text{V} - 11.74\,\text{V} = 3.26\,\text{V}$; ***[2]***
(so the voltage of the non-inverting input of the op amp is around 3 V)

Option G — Electromagnetic waves

11. (a) (i) one point on axis identified – centre of curvature/focus/centre of lens and second point on axis identified – centre of curvature/focus/centre of lens/perpendicular to flat side of lens; ***[1]***
It is acceptable to choose 2 foci, 2 centres of curvature or a mixture.

(ii) one ray drawn correctly;
a second ray drawn correctly;
image correctly located and shown; ***[3]***



(iii) real/inverted/magnified; ***[1]***
Allow ECF from (a)(ii).

(b) (i) central cross shown straight;
sides curved (inwards or outwards); ***[2]***

(ii) rays passing through the edge of the lens are brought to a different focal point than those passing through the centre;
by covering the outer edge of the lens/reducing the aperture (only the centre of the lens is used) bringing the light to one focus; ***[2]***

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

(ii) more electrons are in the higher state than in the ground/lower state; ***[1]***

(b) any sensible suggestion; *(eg eye surgery, cancer treatment)*
brief description given; ***[2]***

eg eye surgery;
laser burns tissue to control leakage of blood vessels in the eye / laser used to destroy cells (to reshape the cornea) to improve eyesight;

13. (a) the waves are coherent so interference occurs;
high intensity sound corresponds to a position where sound constructively interferes/superposes / low/zero intensity sound corresponds to a position where sound destructively interferes/cancels;
high intensity is where the path difference is an integral number of wavelengths;
low/zero intensity of sound is where the path difference is $n+\frac{1}{2}$ wavelengths; ***[3 max]***

(b) $\lambda = \frac{330}{2500} = 0.132\,\text{m}$;

$x = \left(\frac{n\lambda D}{d} = \frac{1.0 \times 0.132 \times 8.0}{1.5} = \right) 0.70(4)\,\text{m}$; ***[2]***

(c) distance doubles so fringe width is halved;
so fringes are encountered at the same rate, no change; ***[2]***

14. (a) (i) evidence of use of a value of $\lambda = 20\,\text{pm}$;

$V = \left(\frac{hc}{e\lambda_{\text{min}}} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.60 \times 10^{-19} \times 20 \times 10^{-12}} = \right) 62\,\text{kV}$; ***[2]***

(ii) the peaks occur as electrons are ejected from the inner shell by the accelerated electrons (from the cathode);
as electrons fall from a higher to a lower level they emit X-ray photons; ***[2]***

(b) $\theta = \sin^{-1}\left[\frac{n\lambda}{2d}\right]$ ***or*** $\sin^{-1}\frac{2 \times 200 \times 10^{-12}}{2 \times 3.6 \times 10^{-10}}$;

$\theta = 34^{\circ}$; ***[2]***

15. (a) the light reflects at the air:oil and the oil:water boundary; *(can be shown on diagram)*
light reflecting from the oil:water boundary interferes with the light reflecting from the air:oil boundary;
depending on the thickness of the oil, different frequencies show constructive/destructive interference (hence coloured fringes); ***[2 max]***

(b) *for constructive interference*:

$\left(2nt = \left[m + \frac{1}{2}\right]\lambda\right)$

$t = \left[m + \frac{1}{2}\right]\frac{\lambda}{2n}$ ***or*** $\left[0 + \frac{1}{2}\right]\frac{520 \times 10^{-9}}{2 \times 1.40}$;

$t = 93\,\text{nm}$; ***[2]***

Option H — Relativity

16. (a) beam X will reach the mirror first;
the speed of light of each beam is constant for all inertial observers;
the left mirror moves towards the beam X while the right mirror moves away from the beam Y; ***[3]***

(b) the beams returning to Daniela occur at one point in space;
if this is simultaneous to Daniela, the event will also be simultaneous to Jaime; ***[2]***

or

beam X has less to go to the mirror and then longer to Daniela, whilst beam Y has longer to the mirror and less to Daniela;
the sum of the times are the same because Daniela is in the middle so they arrive at the same time;

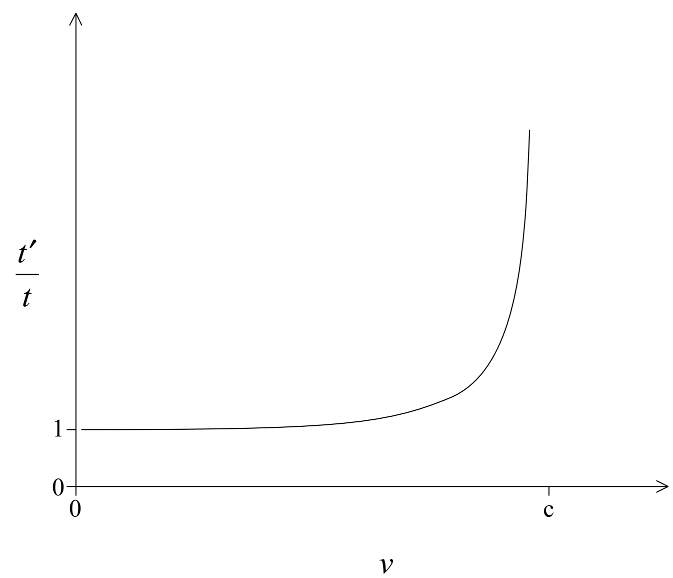
17. (a) the laws of physics are the same for all inertial observers; ***[1]***

(b) (i) $t=\frac{2d}{c}$ and $t'=\frac{d'}{c}=\frac{2}{c}\sqrt{\left(\frac{vt'}{2}\right)^2+d^2}=\frac{2}{c}\sqrt{\left(\frac{vt'}{2}\right)^2+\left(\frac{ct}{2}\right)^2}$;

$\frac{c^2t'^2}{4}=\frac{c^2t^2}{4}+\frac{v^2t'^2}{4}$ which gives $t'^2=t^2+\left(\frac{v}{c}\right)^2t'^2$;

$t'^2\left[1-\left(\frac{v}{c}\right)^2\right]=t^2$; ***[3]***

(ii) line begins at $\frac{t'}{t}=1$ when $v=0$;
line fairly flat until around $v=0.6$ and then asymptotically approaches $v=c$; ***[2]***



18. (a) $t = \left(\frac{d}{v} = \frac{10^4}{0.98 \times 3 \times 10^8} = \right) 3.4 \times 10^{-5}\,\text{s}$;

which is $\frac{3.4 \times 10^{-5}}{2.2 \times 10^{-6}} \approx 15$ decay times; *[2]*

(so very few muons will reach Earth)

or

$d = vt = 0.98 \times 3 \times 10^8 \times 2.2 \times 10^{-6} = 650\,\text{m}$ in one decay time;

in travelling to Earth, there are $\frac{10000}{650} \approx 15$ decay times;

(so very few muons will reach Earth)

(b) (i) $\gamma = \sqrt{\frac{1}{1-0.98^2}} = 5.0$;

$t = \gamma t_0 = 5.0 \times 2.2 \times 10^{-6} = 1.1 \times 10^{-5}\,\text{s}$; *[2]*

(ii) distance travelled in one half-life is

$d = vt = 0.98 \times 3 \times 10^8 \times 1.1 \times 10^{-5} = 3200\,\text{m}$;

for observers on Earth, the muons are able to travel much further compared with those in (a); *[2]*

(so many more will be able to reach the Earth before they have decayed)

19. (a) $u'_x = \frac{u_x - v}{1 - \frac{u_x v}{c^2}} = \frac{0.85c - [-0.85c]}{1 + [0.85]^2}$;

0.99c; *[2]*

(b) (i) $E = (2\left[\gamma m_0 c^2\right] = 2 \times 1.9 \times 0.511 =)1.94$ MeV ***or*** 3.1×10^{-13} J; *[1]*

(ii) total momentum before the collision is zero;

if only one photon is emitted then the total momentum after the collision cannot be zero, otherwise momentum will not be conserved; *[2]*

(iii) $f = \frac{E}{h} = \frac{0.5 \times 1.9418 \times 10^6 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$; *(allow ECF from (b)(i))*

$f = 2.3 \times 10^{20}\,\text{Hz}$; *[2]*

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

or

photon is subject to extreme warping of spacetime;
under these conditions a distant observer observes dilation of the photon period / *OWTTE*;
increase in time period is equal to decrease in photon frequency;

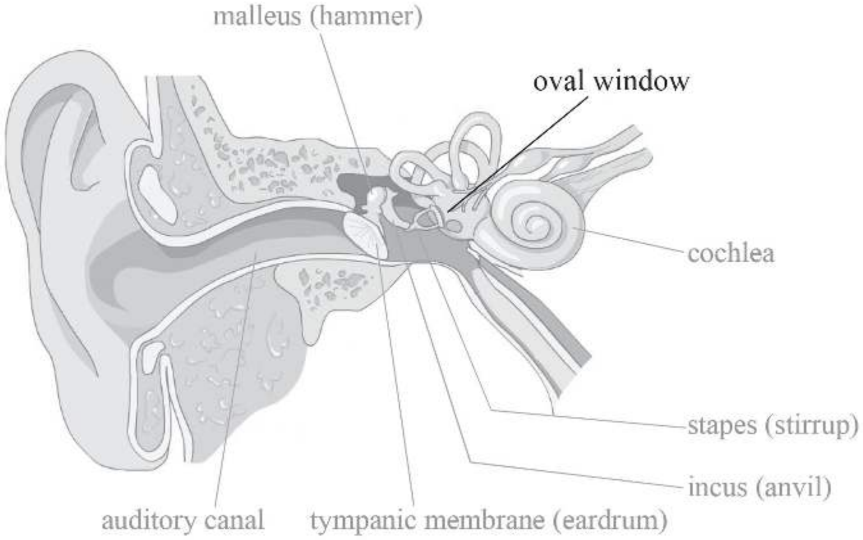
(b) $R_s = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 4.5 \times 10^{31}}{9 \times 10^{16}} = 66700\,\text{m}$;

$\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{R_s}{r}}} = 1.5 = \frac{1.0}{\sqrt{1 - \frac{66700}{r}}}$;

$r = 1.2 \times 10^5\,\text{m}$; ***[3]***

Option I — Medical physics

21. (a) (i) label as shown in the diagram; *[1]*



(ii) the oscillation of the bones/malleus, incus, stapes help to amplify the sound;
the pressure at the stapes is greater than the pressure at the hammer due to a reduction in surface area; *[2]*

(b) (i) $\left(\text{use of } IL = 10\log\frac{I}{I_0}\right)$;

$105 = 10\log\frac{I}{1.0\times10^{-12}}$;

$I = 0.032\,\text{W}\,\text{m}^{-2}$; *(at least 2 significant figures required for this mark)* *[2]*

(ii) $\frac{I_{90}}{I_{105}} = \left(\frac{0.001}{0.032} = \right)0.031$;
which shows that 97 % should be eliminated; *[2]*

22. (a) (i) probability of a single photon being absorbed in 1 m of the material / reference to $I = I_0\, e^{-\mu x}$ with symbols defined; ***[1]***

(ii) $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$;
$= 3.89$ cm; ***[2]***

(b) (i) $\frac{I_{\text{blood}}}{I_{\text{muscle}}} = \frac{I_0 e^{-\mu_{\text{blood}} x}}{I_0\, e^{-\mu_{\text{muscle}} x}} = \frac{e^{-0.178x}}{e^{-0.180x}}$;
$e^{0.002} = 1.002$; ***[2]***

(ii) the difference between the intensities is only around 0.2 %/less than that (2 %) required to provide sufficient contrast between the muscle and the blood;
this is too small to provide a clear difference on the X-ray film; ***[2]***

(c) ratio needs to be 0.98 to show a sharp contrast;
$e^{(0.180-\mu_{\text{blood}})} = 0.98$;
so $\mu_{\text{blood}} = 0.2$ / increase of around 0.02; ***[3]***

(d) low intensity X-rays would not provide sufficient contrast between neighbouring tissues;
enhancement shows a clearer difference in the image; ***[2]***

23. (a) film badge contains photographic film;
which darkens when exposed to radiation;
to monitor the amount of exposure over a period of time;
different filters allow for alpha-radiation, beta-radiation and gamma-radiation to be monitored separately; ***[3 max]***

(b) (i) (a unit-less) quantity which determines the amount of biological damage caused by equal doses of radiation; ***[1]***

(ii) Sr-89 has a relatively short half-life so it will not remain in the body for many years;
Sr-89 will have a high activity to help destroy the cancer cells / Sr-89 has beta particles with the proper range so as not to ionize individuals near the patient; ***[2]***

(iii) $\frac{1}{T_{\text{E}}} = \left(\frac{1}{T_{\text{P}}} + \frac{1}{T_{\text{B}}} = \right)\frac{1}{51} + \frac{1}{50}$;
$T_E = 25(.2)$ days; ***[2]***

(iv) a range of 8 mm inside the body means that the effects are very local;
no/very small amounts of radiation will be detected outside of the body; ***[2]***

(c) treatment may lead to other medical complications;
lack of treatment will allow the cancer to spread/increase pain levels; ***[1 max]***

Option J — Particle physics

24. (a) (i) electromagnetic;
strong; ***[2]***

(ii) they are composed of more than one quark; ***[1]***

(b) (i) W^+; ***[1]***

(ii) u has a baryon number of $\frac{1}{3}$ and $\bar{\text{d}}$ has a baryon number of $-\frac{1}{3}$;
μ^+ and ν_μ both have a baryon number of 0; ***[2]***

(iii) (conversion of mass into kg:)
$100\,\text{MeV}\,\text{c}^{-2} = \left(\frac{100\times10^{6}\times1.6\times10^{-19}}{9\times10^{16}} =\right)1.78\times10^{-28}\,\text{kg}$;
$R = \left(\frac{h}{4\pi mc} = \frac{6.63\times10^{-34}}{4\pi\times1.78\times10^{-28}\times[3\times10^{8}]} =\right)9.9\times10^{-16}\,\text{m}$; ***[2]***
At least 2 significant figures required for the second mark.

(iv) the range is comparable to the separation between adjacent nucleons / *OWTTE*; ***[1]***

25. (a) $E_a^2 = \left(2Mc^2E + [Mc^2]^2 + [mc^2]^2 =\right) 210^2 = 2\times0.511\times E + 0.511^2 + 0.511^2$;
$E = 43.2\,\text{GeV}$; ***[2]***

(b) (i) the electric field provides a potential difference;
this accelerates the particles / this gives energy to the particles; ***[2]***

(ii) electromagnets can produce a much stronger magnetic field (than permanent magnets);
the strength of electromagnets can be made stronger to provide the force for more energetic particles; ***[2]***

(iii) the smaller the radius of the ring the greater (centripetal) acceleration required;
as electrons are accelerated more rapidly, they lose more energy;
energy is lost in the form of radiation; ***[2 max]***

26. (a) high energy particles;
probe the nature of internal structure of hadrons/quarks; ***[2]***

(b) (i) $p=\frac{h}{\lambda}=\frac{6.63\times10^{-34}}{10^{-15}}\left(=6.63\times10^{-19}\right)$;

$E_K=\frac{p^2}{2m}=\frac{\left[6.63\times10^{-19}\right]^2}{2\times9.11\times10^{-31}}\left(=2.4\times10^{-7}\right)$;

$=\frac{2.4\times10^{-7}\text{ J}}{1.6\times10^{-19}\text{ C}}=1.5\times10^{12}\text{ V}$; ***[3]***

(ii) u has charge of $\frac{2}{3}$ and *d* has charge of $-\frac{1}{3}$, so udd gives $\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$;

each quark has spin of $\frac{1}{2}$, two spin up and one spin down $=\frac{1}{2}+\frac{1}{2}-\frac{1}{2}=\frac{1}{2}$; ***[2]***

(c) at low energy the electrons are scattered by the nucleus;
at medium energy the electrons are scattered by particles within the nucleus;
at the highest energy levels the electrons have a small enough de Broglie wavelength to be scattered by the particles inside the hadrons/protons/neutrons; ***[2 max]***
Accept two regions of lower energy.

27. (a) early universe contained slightly more matter particles than anti-matter particles;
due to asymmetry (in the early processes) most of the matter particles were annihilated by anti-matter particles, but left a tiny amount behind (which is what we see in the universe today); ***[2]***

(b) $\left(E_K=\frac{3}{2}\text{kT}\right)$

$T=\frac{2E_K}{3k}=\frac{2\times0.1\times10^{6}\times1.6\times10^{-19}}{3\times1.38\times10^{-23}}$;

$T=7.7(2)\times10^{8}\text{ K}$; ***[2]***