International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

MARKSCHEME

May 2014

PHYSICS

Higher Level

Paper 3

19 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. icy/dusty object;
moving around the Sun on a (highly) elliptical orbit;
when close to Sun likely to display atmosphere (coma)/tail;
when far from Sun (ice re-freezes and) atmosphere no longer present; ***[2 max]***
*Award **[2]** only if it is clearly stated that the object is a part of a Solar system.*

2. (a) balance of two forces/pressures;
(balance) between radiation/pressure and gravitational force/pressure;
(radiation pressure is when) photons/radiation exert outwards force on nuclei/particles;
(gravitational pressure is when) gravitational force between particles/layers of the star acts inwards; ***[3 max]***

(b) whilst on the main sequence hydrogen fusion/burning to give helium;
after leaving the main sequence helium fusion/burning to give carbon; ***[2]***

(c) star in (b) forms red giant, heavier star forms (red) supergiants; *(do not allow "giant")*
star in (b) forms planetary nebula, heavier star goes supernova;
star in (b) forms white dwarf, heavier star forms neutron star/black hole; ***[3]***

3. (a) $-2.89 = 5\log_{10}\left[\frac{d}{10}\right]$;

$d = 10^{0.422}$;

2.6 (pc); *(must see 2+ significant figures to award this mark)* ***[3]***

$(= 3\text{ pc})$

*Award **[2 max]** if $d=3$ (pc) is substituted and shown that left side is almost equal to right side.*

(b) $L\left(= 4\pi b d^2\right) = 4\times\pi\times 1.2\times 10^{-7}\times\left[8.1\times 10^{16}\right]^2$;

9.9×10^{27} (W); ***[2]***

Allow 1.3×10^{28} (W) if candidates use 3 (pc) from (a).

(c) $\frac{\mathrm{M_{Sirius}}}{\mathrm{M_{Sun}}}\left(=\left[\frac{\mathrm{L_{Sirius}}}{\mathrm{L_{Sun}}}\right]^{\frac{1}{3.5}}\right)=\left[\frac{9.9\times 10^{27}}{3.8\times 10^{26}}\right]^{\frac{1}{3.5}}$;

$\mathrm{M_{Sirius}} = 2.5\,\mathrm{M_{Sun}}$; ***[2]***

Allow ECF from (b).

(d) (stellar) parallax;

compare angular direction/position of star at times six months apart (to yield angular change θ);

relative to the background of fixed/distant stars;

use of earth orbital diameter D/1AU to yield distance to star $\left(d = \frac{\mathrm{D}}{\theta}\right)$; ***[4]***

Accept marking points in the form of a diagram.

4. (a) (i) galaxies arranged in clusters (that are themselves arranged in superclusters); ***[1]***

(ii) galaxies/clusters/superclusters move further apart / distance between galaxies/ clusters/superclusters increases; ***[1]***

(b) increase in wavelength / red-shift is observed in light from distant galaxies;

the red-shift increases with distance;

therefore (the metric of) space is expanding (with time) / the separation between galaxies is increasing;

following the Big Bang; ***[3 max]***

Galaxies are moving away from us or from Earth is not enough for the third mark.

Do not award mark for background radiation.

5. assume uniform density of stars;
number of stars in each shell is proportional to [radius of shell]^2;
apparent brightness from shell is inversely proportional to [radius of shell]^2;
light/radiation from shells adds up;
(intensity of shell is independent of radius and) total intensity is infinite / sky is never dark (because infinite universe/infinite number of stars assumed); ***[4 max]***

Option F — Communications

6. (a) amplitude modulation/AM; ***[1]***

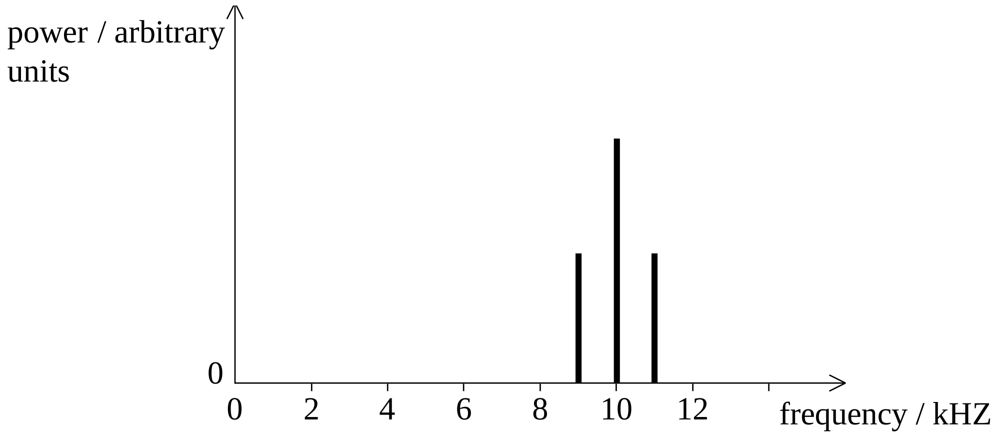
(b) (i) $10\,000\ \mathrm{Hz/s^{-1}}$; ***[1]***
This is a question testing units for this option. Do not award mark for an incorrect or missing unit.

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

(iii) 1000 (Hz); ***[1]***

(c) central peak at the correct frequency $10\,\mathrm{kHz}$; *(allow ECF from (b))*
sidebands at the correct frequency $9\,\mathrm{kHz}$ and $11\,\mathrm{kHz}$; *(allow ECF from (b))*
central peak higher than sidebands; ***[3]***

eg:



7. (a) 4; ***[1]***

(b) at $t = 0\,\mathrm{ms}$, $v = (10.2\,\mathrm{mV} \rightarrow 10\,\mathrm{mV} \rightarrow)1010$;
at $t = 1\,\mathrm{ms}$, $v = (12.2\,\mathrm{mV} \rightarrow 12\,\mathrm{mV} \rightarrow)1100$;
at $t = 2\mathrm{ms}$, $v = (15.2\mathrm{mV} \rightarrow 15\mathrm{mV} \rightarrow)1111$; ***[2 max]***
Allow ECF if less than 4 bits quoted in (a).

(c) sampling rate/bandwidth too low;
number of bits/resolution/quantization levels too few;
change of signal between successive samples too high / *OWTTE*; ***[2 max]***

(d) $= \dfrac{120 \times 8}{1.3}$;
$= 740\,(\mathrm{kbit\,s^{-1}})$; ***[2]***

8. (a) *A*: polar-orbiting;
B: equatorial/geostationary/geosynchronous; ***[2]***

(b) type B;
because they are always above the same point on the Earth's surface; ***[2]***

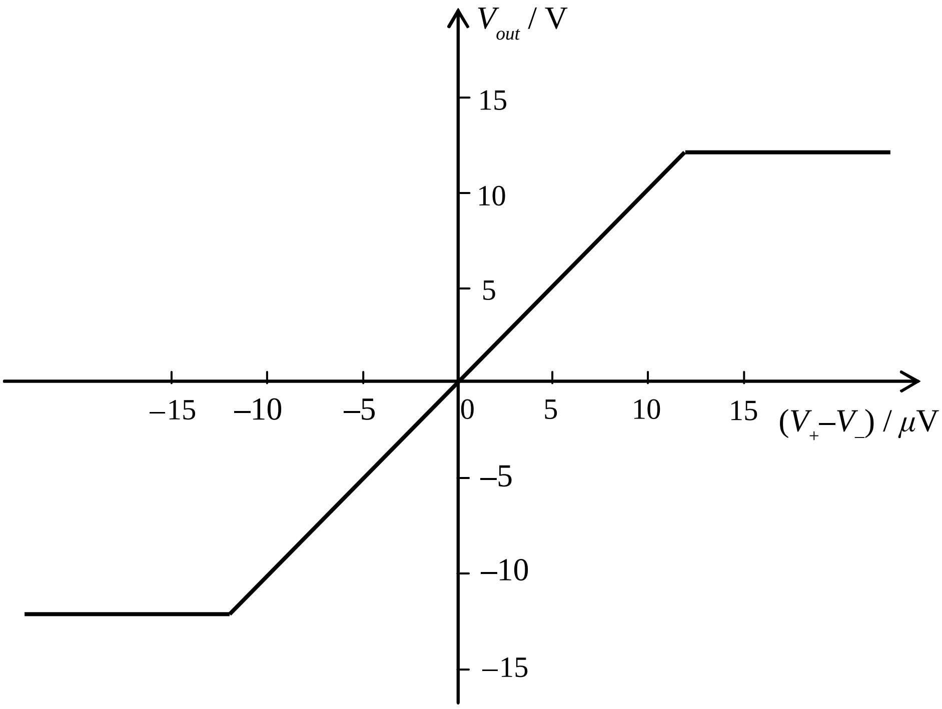
(c) two frequencies required / up-link and down-link frequencies are kept separated;
to avoid interference between the signals; ***[2]***

9. (a) very large / infinite; *(allow hundreds of MΩ and above)* ***[1]***

(b) 8 (V) ;
−12 (V) ; ***[2]***

(c) linear region shown;
with slope 10^6 ;
saturation regime shown; (*judge by eye) (accept values in the range of 10 V–14 V)* ***[3]***

eg:

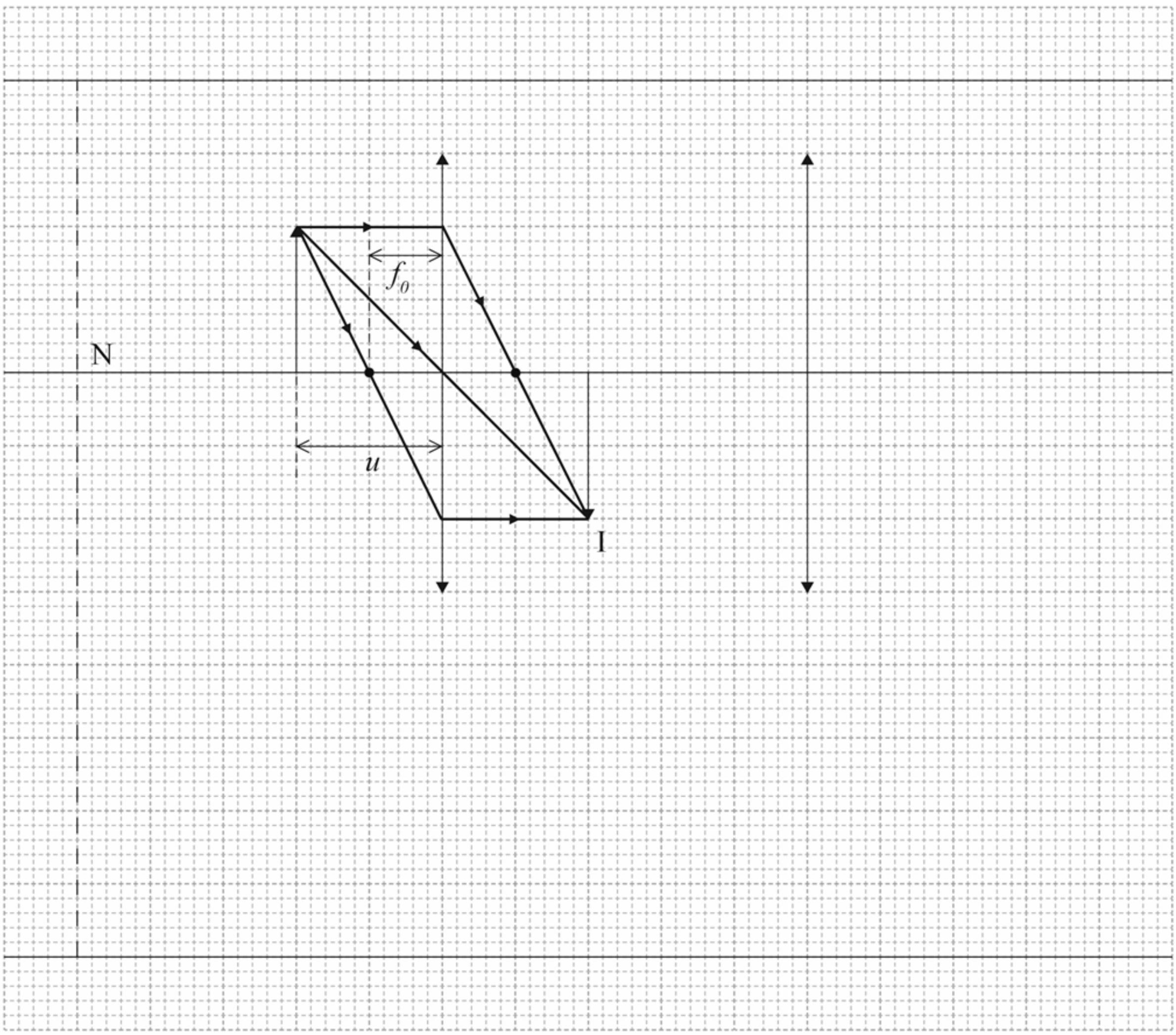


(d) (i) comparator; ***[1]***

(ii) $V_- = 6\,(\text{V})$;
$\frac{R_2}{R_1} = 3$;
$R_2 = 30\,(\text{k}\Omega)$; ***[3]***
*Award **[3]** for a bald correct answer.*

Option G — Electromagnetic waves

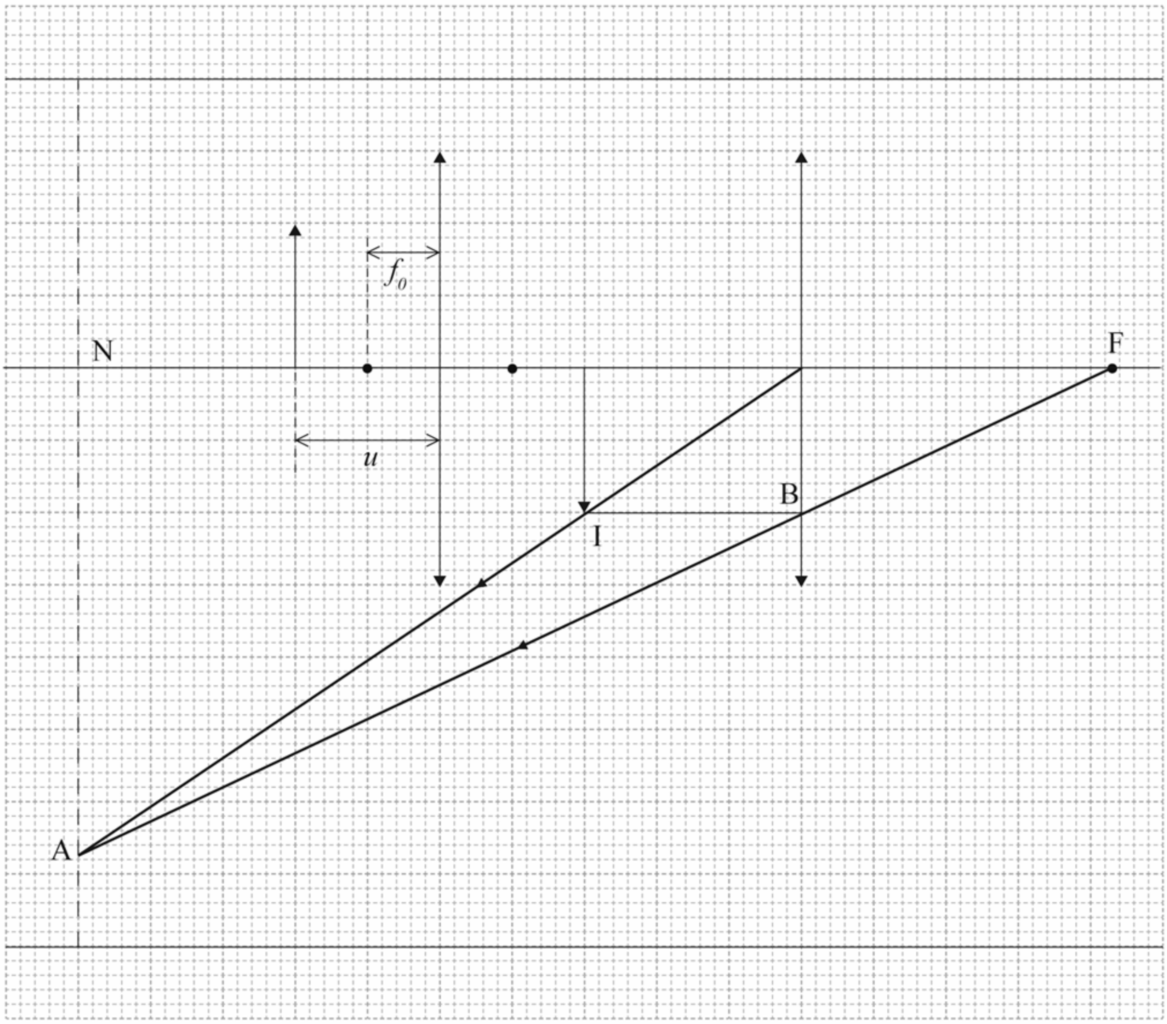
10. (a) (i) any two standard rays out of the three shown below;
converging to locate the image; ***[2]***



(ii) (image is real) because rays of light/energy pass through it; ***[1]***

(b) (i) the closest distance the unaided human eye can focus (without undue strain); ***[1]***
Do not accept 25 cm without explanations.

(ii) standard ray through the center of the eyepiece to locate point A;
standard ray through points A and B;
extrapolated to the principal axis to locate the focus F, 10.7 cm from the eyepiece; *(allow focal lengths between 9 cm and 12.5 cm if the two standard rays are clearly identified)* **[3]**



or

$v = -25\,\text{cm}$;

$u = +7.5\,\text{cm}$;

$$f = \left[\frac{1}{u} + \frac{1}{v}\right]^{-1} \left(= 10.7\,\text{cm}\right);$$

(iii) counting small squares, size of final image $= 33.3$ and size of object $= 10$;

$$m = \frac{33.3}{10} = 3.3;$$ **[2]**

or

$m_1 = 1$ and $M_2 = \left(\frac{25}{7.5} = \right) 3.3$;

$M = (m_1 \times M_2 =) 3.3$;

11. (a) waves of different wavelength/frequency;
travel at different velocities;
the index of refraction of the medium depends on wavelength/frequency; ***[2 max]***

(b) during this motion the charge oscillates/accelerates;
(oscillating/accelerating) charges radiate/produce (varying) electric/magnetic fields / produce electromagnetic waves; ***[2]***

12. (a) (i) intensity at P is zero hence complete destructive interference occurs;
point P is at the same distance from A and B / path difference is zero;
destructive interference comes from a 180° phase difference in the signals; ***[3]***

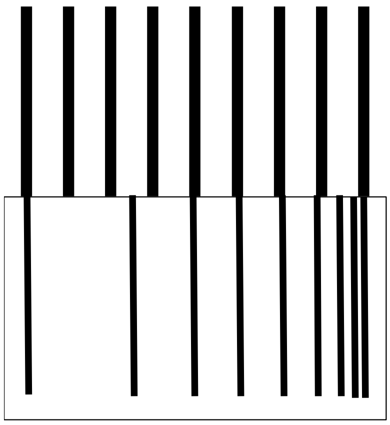
(ii) separation between minima $s = 3$ (km);
$\frac{D}{d} = \left(\frac{s}{\lambda} = \frac{3000}{40} = \right) 75$; ***[2]***

(b) R is always equidistant to stations A and B/signals from A and B are always out of phase;
intensity is always zero; ***[2]***

13. (a) $\lambda = \left(2D\tan\theta = \right) 2\times 0.30\tan 10^{-3}$ ***or*** $2\times 0.30\sin 10^{-3}$;
$\lambda = 6.0\times 10^{-7}$ (m); ***[2]***
*Award **[1 max]** for use of degrees instead of radians giving $\lambda = 1.0\times 10^{-8}$ (m).*

(b) decreasing distance from left to right;
distance larger than original at left and shorter than original at right; ***[2]***

eg:



14. (a) $V = \left(\frac{hc}{e\lambda} = \right)\frac{hc}{e \times 2.5 \times 10^{-11}\,(\text{m})}$;
$V = 50\ (\text{kV})$; ***[2]***

(b) change temperature of cathode / change cathode current;
increased temperature/current gives increased intensity; ***[2]***

or

change (accelerating) voltage;
increased voltage gives increased intensity;

(c) the accelerated electrons remove electrons from the inner shells of the target atoms;
electrons in high excited states of the target atoms make transitions to the ground state;
emitting photons with energies typical of the target material; ***[2 max]***

Option H — Relativity

15. (a) a co-ordinate system (in which measurements of distance and time can be made);
which is not accelerating;
in which Newton's laws are valid; ***[2 max]***

(b) (i) $\left(\frac{10}{0.90c}=\right)11\text{ yr}$; ***[1]***
$(=3.5\times10^{8}\text{ s})$
This is a question testing units for this option. Do not award mark for an incorrect or missing unit.

(ii) distance according to spaceship observer $=\frac{10}{2.3}(=4.3\text{ly})$;
so time for spaceship $=\left(\frac{4.3}{0.90}=\right)4.8\,(\text{yr})$; ***[2]***

(c) between two events occurring at the same point in space / shortest time measured;
so proper time interval measured by observer on spaceship; ***[2]***
Do not award second marking point unless a reason has been attempted.

(d) speed of light is the same for both observers O and S / events simultaneous in stationary reference frame are not (necessarily) simultaneous in moving reference frame;
S is moving so PS will be longer than QS when light reaches S;
so if light arrives simultaneously then light from P will have been in transit for longer than Q;
therefore P emits a flash before Q; ***[3 max]***

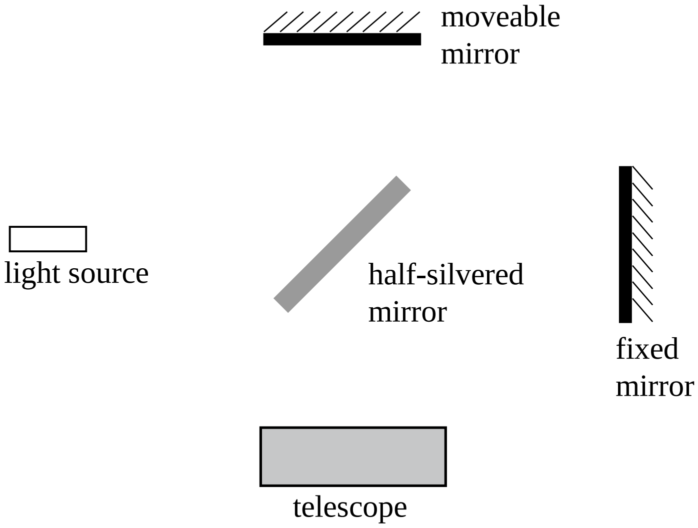
16. total energy of proton $=eV+$ rest mass;
$([2500+938]\,\text{MeV}=)\,3438$;
$p^2c^2=\left(E_{\text{tot}}{}^2-m_0{}^2c^4=\right)3438^2-938^2$;
$p=3.3\,(\text{GeV c}^{-1})$ ***or*** $1.76\times10^{-18}\,(\text{kg ms}^{-1})$; ***[4]***

***Note**: The question paper stated the units of potential difference in GeV. Watch for answers stating that the unit of potential difference is V, not eV. For such answers without calculation, award **[1]**.*

*Award **[4]** for correct use of potential difference (2.5 GeV) divided by e. ie* $\frac{2.5\times10^{9}\,(eV)}{1.6\times10^{19}\,(C)}=1.56\times10^{28}\,(V)$.

17. (a) half-silvered mirror in correct position / *OWTTE*;
(fixed) mirror in correct position; ***[2]***
*Award **[1 max]** when labels are missing and mirrors are at the correct position.*
Ignore a reference to mercury and/or firm table, on which this apparatus is mounted.

eg:



(b) light from the two beams causes an interference pattern;
they rotated the apparatus (by 90°) / viewed pattern at different times of year;
looking for a shift in the interference pattern;
that could be measured/cancelled out by moving moveable mirror (to assess size of effect); ***[3 max]***

(c) no interference shift found;
no ether / absolute frame of reference; ***[2]***

18. (a) a frame of reference accelerating in outer space is equivalent to a frame of reference at rest in a gravitational field / an inertial frame of reference in outer space is equivalent to a freely falling frame of reference in a (uniform) gravitational field; ***[1]***
*Award **[0]** for only "gravitational and inertial mass are equivalent".*

(b) (i) light source appears to be moving away from the observer;
so there is a red-shift (according to the Doppler effect); ***[2]***

or

spaceship (by equivalence) can be regarded as (at rest) in a gravitational field;
photons lose energy in reaching observer (so frequency must be reduced);

(ii) the planet has a gravitational field;
so (by equivalence) the situation is as though light source is near a planet;
f is still observed to be less than f_0 / period of the light can be taken as unit of time;
this can be interpreted as an increase in the time for emission of one wavelength / increase in the period (*ie* time is dilated); ***[3 max]***

19. mention of gravitational lensing;
galaxy has a very large mass/gravitational field;
this field/mass bends the direction of light emitted by the quasar;
spacetime is distorted by this field/mass; ***[3 max]***
Award ***[1 max]*** *for a diagram showing only a curve joining the quasar and the Earth.*
Award ***[3]*** *for an annotated diagram.*

Option I — Medical physics

20. (a) from 20 Hz to 20 kHz; ***[1]***

Allow lower limit answers in the range of 20 Hz to 50 Hz and upper limit answers in the range of 16 kHz to 20 kHz.

(b) intensity is power per unit area ***or*** $I = \frac{P}{4\pi r^2}$ with symbols defined;

intensity level takes into account (the logarithmic) response of the human ear to intensity / $IL = 10\lg\frac{I}{I_0}$, where $I_0 = 1.0\times10^{-12}\ \mathrm{W\,m^{-2}}$; ***[2]***

(c) from the graph 75 (dB) and 85 (dB);

$I_{\text{low}}\left(= I_0 \times 10^{\frac{85}{10}}\right) = 3.2\times10^{-4}\ (\mathrm{Wm^{-2}})$ and $I_{\text{high}}\left(= I_0 \times 10^{\frac{75}{10}}\right) = 3.2\times10^{-5}\ (\mathrm{Wm^{-2}})$;

total intensity $\left(= I_{\text{low}} + I_{\text{high}}\right) = 3.5\times10^{-4}\ (\mathrm{Wm^{-2}})$; ***[3]***

As it is assumed that all noise is split only into high-frequency and low-frequency without overlap.

(d) permanent damage to exposed cochlear hair cells;
leads to selective frequency losses;
tinnitus/constant ringing (sensation); ***[2 max]***

21. (a) 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]***

(b) (i) at $0.1\,\mathrm{MeV}$, $\mu = 30\,(\mathrm{m^{-1}})$;

$0.1 = e^{-30x}$;

$x = \frac{\ln 0.1}{-30}$;

$x = 0.077$ (m); ***[4]***

(ii) (at $10\,\mathrm{MeV}$,) μ is smaller (than at $0.1\,\mathrm{MeV}$);
so ($10\,\mathrm{MeV}$ X-rays are) more penetrating; ***[2]***

Award second mark only if first mark has been awarded.

(c) the screen absorbs X-rays and gives off light;
so the film's exposed areas become more visible / film is (more) sensitive to light; ***[2]***

(d) *advantage:* better quality image / better resolution / more detailed / 3D not 2D;

disadvantage: longer scan time / greater exposure to X-ray / worse for claustrophobic patients; *(do not allow "more expensive")* ***[2]***

22. (a) absorbed dose is energy absorbed per unit mass / $D = \frac{E}{m}$ with symbols defined;

dose equivalent takes into account the biological damage produced by different types of radiation / $H = QD$ with symbols defined; ***[2]***

(b) $D = \left(\frac{0.65}{75} =\right) 8.7 \times 10^{-3}\,(\mathrm{J\,kg^{-1}})$;

$Q = \left(\frac{H}{D} =\right) \frac{55 \times 10^{-3}}{8.7 \times 10^{-3}} = 6.3$;

neutrons; ***[3]***

(c) (i) physical half-life is the time it takes for the activity of a sample to halve/for half of the radioactive nuclei to decay;
biological half-life is the time it takes for the body to remove/eliminate half the amount of a given dose; ***[2]***

(ii) $T_{\mathrm{E}} = \left(\frac{T_{\mathrm{B}} T_{\mathrm{P}}}{T_{\mathrm{B}} + T_{\mathrm{P}}} =\right) \frac{0.7 \times 4}{0.7 + 4}\,(\text{days})$;

$T_{\mathrm{E}} = 0.6\,\text{days}$; ***[2]***

This is a question testing units for this option. Do not award second marking point for an incorrect or missing unit.

(iii) isotope Y has a suitable physical and effective half-life / isotope X has too small physical half-life;
so the patient receives from Y a more effective dose over a reasonable time; ***[2]***

Option J — Particle physics

23. (a) π^- / antiparticle of π^+; *[1]*
Do not award mark if sign is omitted.

(b) (i) (electro) weak; *[1]*

(ii) gluon/photon; *[1]*

(c) (strangeness is not conserved in interaction B) but this is not necessary for a weak interaction;
strangeness is conserved in interaction C therefore decay is possible; *[2]*
Allow ECF if B identified as strong/gravitational/electromagnetic in (b)(i).

24. (a) $R = \dfrac{hc}{4\pi \times 1.35 \times 10^8 \times 1.6 \times 10^{-19}}$;
0.73 (fm);
(diameter of proton is about 10^{-15} m) *[2]*

(b) (quarks are confined) a single quark cannot be observed/exist outside nucleon as the interaction strength increases with separation;
(so the) energy supplied will create a hadron/quark-antiquark pair (such as π meson) rather than a free quark; *[2]*

25. (a) alternate anodes connected to same polarity; ***[1]***

(b) (i) acceleration occurs between anodes;
force exerted on protons by the potential difference/electric field between anodes;
potential difference/electric field reverses while protons are inside anode (where there is no acceleration); ***[3]***

(ii) protons get faster;
alternating potential difference has constant frequency;
anode length must increase so that time in anode is constant; ***[3]***

(c) (i) $2230^2 = 2\times 938E + 2[938]^2$;
$(E = 1710\,\text{MeV})$
so kinetic energy of proton must be $(1710 - 938 =)770\,(\text{MeV})$; ***[2]***

(ii) $\left(\frac{1}{2}[2230 - 2\times 938] =\right)177\,\text{MeV}$ per particle;
much less energy required in synchrotron; *(allow this marking point without calculation)* ***[2]***
This is the unit question in the option. Do not award first mark without unit or for incorrect unit.

26. (a) (i) Z (boson) / Z^0 / boson; ***[1]***

(ii) Z is massive/has mass; ***[1]***

(b) neutral current interaction (mentioned);
which is only observed with a weak/electroweak (interaction);
as predicted by the standard model; ***[2 max]***

(c) constituents of standard model are point objects, extended in string theory;
spacetime is multi-dimensional, standard model is 3D (time); ***[2]***

27. (a) 10^{23}; *(accept answers in the range 10^{22}–10^{27})* ***[1]***

(b) energy of photon $=\left(\frac{1}{2}k\text{T} =\right)7\times 10^{-15}\,(\text{J})$;
energy required for electron-positron pair $= 1.6\times 10^{-13}\,(\text{J})$;
this is more than energy of photon so large-scale pair production unlikely;
some electron-positron pair production always possible but on small scale only; ***[3 max]***
Accept $\frac{3}{2}kT$.