International Baccalaureate®
Baccalauréat International
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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. (a) (i) stars, and not planets, have cores undergoing fusion;
stars have much greater mass/luminosity/absolute magnitude/temperature than planets;
planets reflect starlight rather than emit;
planets in our solar system can show retrograde motion, stars cannot; ***[1 max]***
Allow other sensible answers.

(ii) stars in a stellar cluster are close to each other/kept together by gravitation, the stars in a constellation are not; ***[1]***

(b) (i) the lines in the (absorption) spectrum of the star (correspond to hydrogen wavelengths); ***[1]***

(ii) the gravitational force that tends to collapse the star is balanced by a force due to radiation pressure; ***[1]***

(c) peak wavelength is at 400 (nm); *(accept answers in the range of 380 to 420 (nm))*
$T = \left(\frac{2.9\times10^{-3}}{400\times10^{-9}} =\right) 7250\,(\text{K})$; *(accept answers in the range of 6900 to 7600 (K))* ***[2]***
*Award **[2]** for a bald correct answer.*

2. (a) (i) (apparent) brightness; ***[1]***

(ii) the star expands and contracts / the star's radius varies / the star's surface temperature varies / the star's surface area varies; ***[1]***

(b) period is 6.6 days; *(allow ± 0.4 days)*
$M = (-2.81\lg_{10} 6.6 - 1.43 =) - 3.73 \pm 0.07$;
average apparent magnitude *m* is 15.55 ± 0.05;
use of $m - M = 5\lg_{10}\frac{d}{10}$ to give $d = 10\times10^{\frac{15.55-(-3.73)}{5}}$;
$= 72$ (kpc); *(accept answers in the range of 68 to 75 (kpc))* ***[5]***
*Allow ECF **[4 max]** if value other than 6.6 days is used, or value other than 15.55 is used for m, or value other than –3.73 for M.*

(c) $L = 4\pi d^2 b$; *(marks are always for the formula re-arrangement or use)*
$L = 4\pi\left(72\times10^3\times3.26\times9.46\times10^{15}\right)^2\times1.5\times10^{-14}$;
$L = 9.3\times10^{29}$ (W); *(accept answers in the range of 8.5×10^{29} to 10×10^{29} (W))* ***[3]***
*Award **[3]** for a bald correct answer.*
Watch for ECF from (b).
If d is left in pc, do not allow ECF for third marking point.

3. (a) electromagnetic radiation in the microwave region;
black body radiation (at a temperature of about 3 K);
(almost) isotropic/uniform radiation;
radiation that fills the universe/exists everywhere/has no obvious point of origin; ***[2 max]***

(b) CMB radiation was a prediction of the Big Bang model;
CMB "temperature" is consistent with a universe that has cooled from an initial hot state;
CMB wavelength is consistent with a universe that has expanded from an initial hot, dense state;
CMB isotropy/uniformity is consistent with its origin in the very early universe; ***[2 max]***

4. (a) from the mass–luminosity relation, Achernar has a higher luminosity; *(reference to mass–luminosity is essential)*
so it is above/to the left of the Sun on the main sequence / temperature increases with luminosity in the main sequence; ***[2]***
Ignore irrelevant statements that $L = \sigma A T^4$.
Allow second marking point even if only mass is discussed.

(b) Achernar has greater luminosity/temperature and so fuses hydrogen at a (disproportionately) higher rate than the Sun / *OWTTE*;
so it will run out of hydrogen/move to red giant region in less time than the Sun / *OWTTE*; ***[2]***

(c) (i) the remnant mass/the mass of its core/the mass after the supernova stage; *(do not allow "mass" bald)*
must be between the Chandrasekhar and Oppenheimer limits / $1.4 M_{\odot} < M_{\text{core}} < 3M_{\odot}$; *(allow answer in words or numerical values)* ***[2]***
Allow $2.5 M_{\odot}$ *to* $3M_{\odot}$ *as O–V limit.*

(ii) detection of EM radiation from pulsars/stars that pulsate / stars whose intensity varies rapidly / *OWTTE*; ***[1]***
Accept answers that refer to any regions of the electromagnetic spectrum.

5. (a) the galaxy is moving away from the Earth and so the wavelength is Doppler/Red shifted; ***[1]***

or

the universe is expanding and so the space between galaxies is stretched/increases and this means that the wavelength of the received light will also be stretched/increased;
Do not accept answers such as "the galaxy is red-shifted".

(b) $v = \left(\frac{\Delta\lambda}{\lambda}c = \frac{682-656}{656}\times 3\times 10^{8} = 3.96\times 10^{-2}\times 3\times 10^{8} = \right)1.2\times 10^{4}\,(\mathrm{km\,s^{-1}})$;

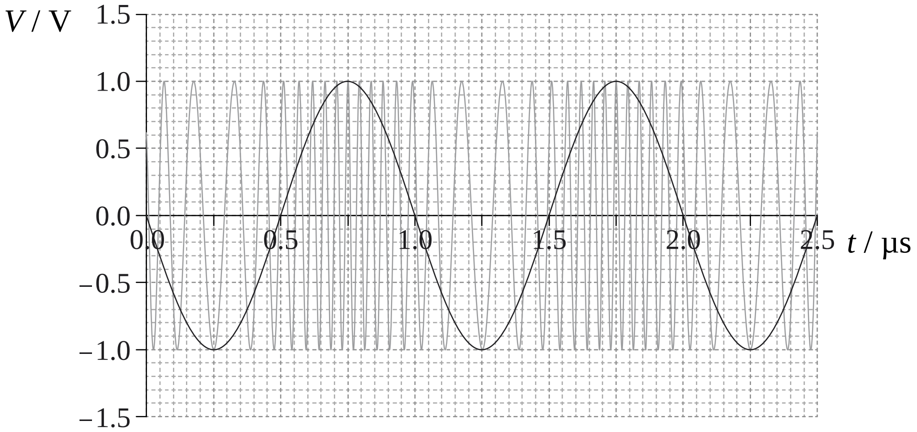
$d = \left(\frac{v}{H_0} = \frac{1.2\times 10^{4}}{74} = \right)160\,(\mathrm{Mpc})$; *(allow 5×10^{24} (m))* ***[2]***

*Allow ECF from first marking point for **[1 max]**.*
For example use of 682 in denominator also giving 160/155 (Mpc).
*Award **[0]** for second marking point if 160 pc, 160 kpc and 160 Gpc are given. These are power of ten errors, not unit errors.*

Option F — Communications

6. (a) (i) the modification of a carrier's frequency by an amount that depends on the signal wave's displacement;
while leaving the amplitude constant; ***[2]***

(ii)



correct amplitude (1 V);
correct period shown □ 1.0 μs ; ***[2]***
Allow inverse of waveform shown.

(b) (i) there are 15 full waves in 1.0 μs so the frequency is 15 (MHz); ***[1]***
Allow 14 to 16 (MHz).

(ii) period of signal wave is 1.0 (μs);
and so frequency is 1.0 (MHz); *(allow ECF from (a)(ii))* ***[2]***
*Warning: it easy to mistakenly award only **[1]** for a correct response.*

(c) *advantage*: ***[1 max]***
better signal to noise ratio / information transmitted with less power / greater bandwidth;
Do not accept vague terms such as "better quality".
Allow other valid responses.

disadvantage: ***[1 max]***
complex circuits / smaller range; ***[2]***
Do not accept "expensive".
Allow other valid responses.

7. (a) there are 8 samples during 1.0 ms/the period of sampling is $\frac{1.0}{8} = 0.125$ (ms);

so the sampling frequency is $\left(\frac{10^3}{0.125} =\right) 8.0$ (kHz); ***[2]***

Allow ECF for incorrect value used from first marking point.

(b) (the quantization error is 1.0 V so) the number of levels is $\frac{12}{1} = 12$;

12 is 1100 so we need 4 bits; *(allow ECF from first marking point)* ***[2]***
Accept bald correct statement.

(c) the voltage is 7 V and so 0111; *(all four bits are required)* ***[1]***
Try to allow ECF if quantization error other than 1.0 V was assumed in (b).

8. (a) the loss of power in the transmission of a signal / *OWTTE*; ***[1]***

(b) (i) power when signal to noise ratio is 35 dB is

$$\left(10\lg\frac{P_{\text{signal}}}{52\times10^{-12}} = 35 \Rightarrow P_{\text{signal}} = 52\times10^{-12}\times10^{3.5} =\right) 1.6\times10^{-7}\text{ (W)};$$

attenuation is $\left(10\lg\frac{88\times10^{-3}}{1.6\times10^{-7}} =\right) 57.4$ (dB);

distance $= \left(\frac{57.4}{2.6} =\right) 22$ (km); ***[3]***

*Award **[3]** for a bald correct answer.*

Accept alternative approaches eg:

$10\lg\left(\frac{P_s}{P_n}\right) = 92.3\text{(dB)}$;

$92.3 - 35 = 57\text{ (dB)}$;

$\frac{57}{2.6} = 22\text{ (km)}$;

*Award **[3]** for a bald correct answer.*

(ii) speed of light in core of fibre is $\left(\frac{5.6\times10^6}{28\times10^{-3}} =\right) 2.0\times10^8\ (\text{m s}^{-1})$;

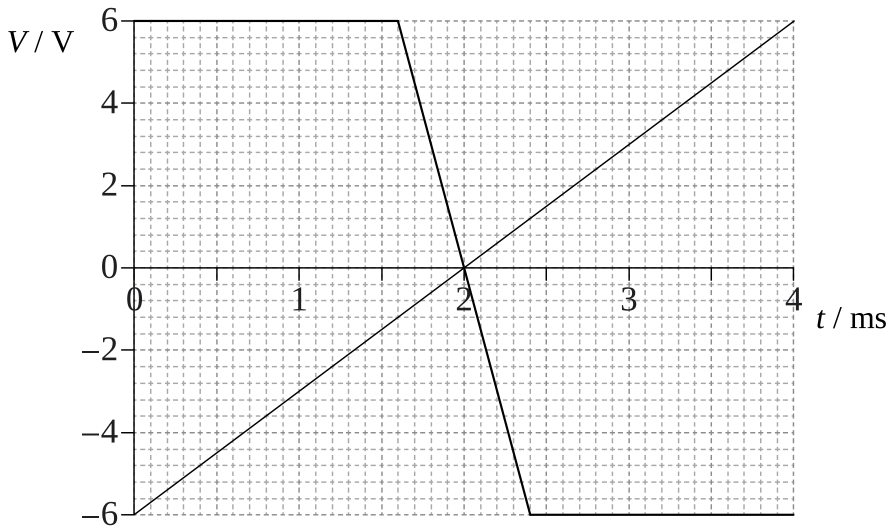
$n = \left(\frac{3.0\times10^8}{2.0\times10^8} =\right) 1.5$; ***[2]***

9. (a) (i) infinite (open loop) gain / infinite input resistance/impedance / zero output / infinite bandwidth / infinite slew rate; ***[1]***

(ii) $G = \left(-\frac{R_F}{R} = -\frac{75}{15} = \right) -5.0$; *(negative sign required)* ***[1]***

(iii) $V_{in} = \frac{6.0}{-5.0} = -1.2\,(\text{V})$; *(watch for ECF from (a)(ii))* ***[1]***

(b)



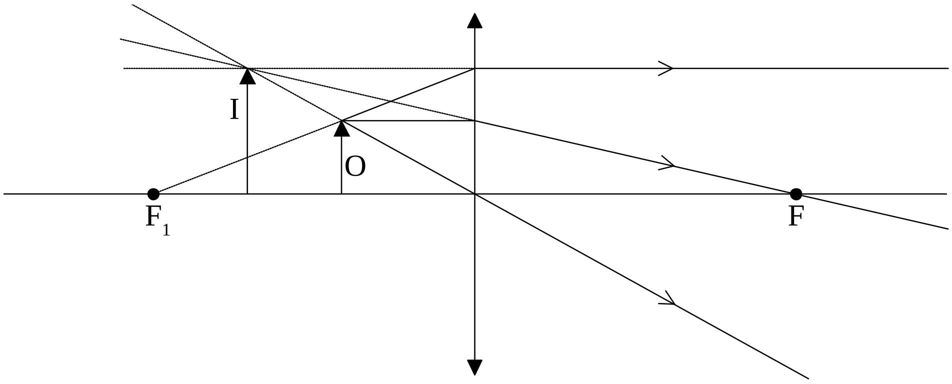
<u>slew gradient</u> negative; *(allow ECF from (a)(iii))*
saturation voltage $+6\,\text{V}$ <u>and</u> $-6\,\text{V}$; *(both needed)*
switches at $\pm 1.2\,\text{V}$ (reaches saturation at $1.6\,\text{ms}$ <u>and</u> $2.4\,\text{ms}$); *(both needed)* *(allow ECF from (a)(iii))* ***[3]***
In third marking point allow + or – one grid square.
Allow second and third marking point independently from first marking point.

10. mobile phone sends signal to base stations;
cellular exchange selects base station with strongest signal;
cellular exchange allocates frequency;
cellular exchange allocates different base station as passenger changes cell;
PSTN forwards call to PSTN of other country; ***[4 max]***

Option G — Electromagnetic waves

11. (a) (i) the point on the principal axis;
through which rays parallel to the principal axis pass after going through the lens / from which rays are parallel to the principal axis after passing through the lens; **[2]**
Accept marking points on a labelled diagram.

(ii)



any correct ray of the three shown in the diagram;
second ray correct;
image shown correctly, between O and F_1; **[3]**
Accept rays without arrows and solid construction lines back to the image.

(b) (i) closest point on which the eye can focus (comfortably); *(allow closest distance)* **[1]**

(ii) gives maximum angular magnification (without straining the eye); **[1]**

(c) (i) separation $= 96$ (cm); **[1]**

(ii) $M = \left(\frac{f_o}{f_e} =\right)\frac{90}{6.0}$;
$M = 15$; **[2]**

12. (a) (i) constant/zero phase difference (between the light waves); ***[1]***

(ii) single/same wavelength/frequency; *(allow "narrow band" OWTTE)* ***[1]***
Do not allow "single colour".

(b) 180° / π rad; ***[1]***
Do not accept $\frac{\lambda}{2}$.

(c) (i) <u>use</u> of $\lambda = \frac{sd}{D}$;
$s = \underline{2} \times 1.8$ (mm); *(award this mark for any evidence for the factor of 2)*
$\lambda = \frac{2 \times 1.8 \times 10^{-3} \times 0.30 \times 10^{-3}}{1.5}$ / *OWTTE*;
$(= 7.2 \times 10^{-7}$ m$)$ ***[3]***
Exact answer is given, award marks for correct working.

(ii) 3.6×10^{-7} m ***or*** 360 nm; ***[1]***
Allow ECF from (c)(i).

(d) <u>use</u> of $d = \frac{n\lambda}{\sin\theta}$;
$d = \frac{3 \times 720 \times 10^{-9}}{\sin 39^\circ} = 3.4 \times 10^{-6}$ (m);
$N = \left(\frac{1}{3.4 \times 10^{-6}} =\right) 2.9 \times 10^{5}$; ***[3]***
*Award **[3]** for a bald correct answer.*
ECF examples:
*Award **[2 max]** if n=2 is used (gives* 4.4×10^5 *).*
*Award **[2 max]** if* 78° *is used (gives* 4.5×10^5 *).*
*Award **[2 max]** if* 13° *and n=1 used (gives* 3.1×10^5 *).*

13. (a) *Look for the following elements on the labelled diagram.*
source of electrons / electron beam;
shows accelerating potential difference with negative to filament;
evacuated X-ray tube;
<u>metal target</u> / emission of X-rays on collision; ***[3 max]***
*Award **[1 max]** for complete absence of labels.*

(b) characteristic X-ray spectrum originates with electrons ejected (from inner shells/energy levels); *(allow excite (BOD) instead of eject)*
energy of (accelerated) electrons is not enough to remove electrons / accelerating pd is too small; ***[2]***

14. (a) use of $m = 1$;
$2 \times 1.51 \times t = 1 \times 579 \times 10^{-9}$;
$t = 1.92 \times 10^{-7}$ (m); ***[3]***
Award ***[3]*** *for a bald correct answer.*
Award ***[2 max]*** *for use of* $m = \frac{1}{2}$ *giving* 9.6×10^{-8} *(m).*
Award ***[2 max]*** *for answer of* $\frac{\lambda}{2}$ *for air* $(2.9 \times 10^{-7}$ *(m)).*

(b) intensity increases;
intensity then decreases and increases repeatedly;
when thickness becomes very large the intensity becomes constant; ***[2 max]***

Option H — Relativity

15. (a) because the events occur at the same place/point in space for this observer; ***[1]***
Do not allow "events within the same reference frame".

(b) (i) $t = \left(\frac{12}{0.60\text{c}} = \right) 20\,(\text{yr})$; ***[1]***

(ii) $\gamma = \left(\frac{1}{\sqrt{1 - 0.60^2}} = \right) 1.25$; *(allow implicit value)*

$t_{\text{rocket}} = \left(\frac{20\,\text{yr}}{\gamma} = \right) 16\,(\text{yr})$; (*allow ECF)* ***[2]***

*Award **[2]** for a bald correct answer.*

(c) (i) $L = \left(\frac{12\,\text{ly}}{\gamma} = \right) 9.6\,(\text{ly})$; *(allow ECF from (b)(ii))* ***[1]***

(ii) $v = \left(\frac{9.6\,\text{ly}}{16\,\text{y}} = \right) 0.60\text{c}$; *(allow ECF from (b)(ii) and (c)(i))* ***[1]***

(iii) (by principle of relativity this should be the) same as the speed of the spaceship relative to Earth; ***[1]***

(d) both signals travel at the same speed c;
Judy must agree that the signals arrive at S simultaneously / *OWTTE*;
for Judy, observer S moves away from the signal traveling from P/towards the signal traveling from Earth;
for Judy the signal from P has further to travel to reach S – so was emitted first; ***[3 max]***
Do not accept explanations based on Judy approaching P or seeing/receiving the signal from P first as this is irrelevant.
*Award **[0]** for a bald correct answer.*

(e) (i) Peter on Earth measures that the time elapsed is shorter for Judy in the spaceship because he considers himself to be at rest;
but Judy considers herself to be at rest in which case the time elapsed will be shorter for Peter; ***[2]***
Allow answers based on Peter aging more than Judy and vice versa.

(ii) the situation is not symmetrical;
because Judy, in the spaceship, changed inertial frame of reference for the return trip (and Peter on Earth does not) / Judy accelerated and Peter did not;
Peter/Earth twin does age more than Judy/other twin; ***[2 max]***

16. (a) (i) <u>use</u> of $E^2 = (\text{m}c^2)^2 + p^2c^2$;

by conservation of energy, total energy of pion is $\frac{770}{2} = 385\,\text{MeV}$;

$385^2 = 140^2 + p^2c^2$; *(award **[3]** immediately if this marking point is seen)* ***[3]***

Solving for momentum gives the answer $p = 359\,\text{MeV}\,c^{-1} \approx 360\,\text{MeV}\,c^{-1}$.

Answer is given, marks are for correct working only.

No ECF if wrong energy used.

(ii) $\gamma = \frac{385}{140}\,(= 2.75)$;

hence $v = \sqrt{1 - \frac{1}{\gamma^2}}c = \sqrt{1 - \frac{1}{2.75^2}}c\ (= 0.932\text{c})$; ***[2]***

Answer given, award marks for working only.

Watch for ECF from (a)(i) or first marking point.

(iii) $(770 - 2 \times 140) = 490\,\text{MeV}\,\text{c}^{-2}$; ***[1]***

(b) $u = \left(\frac{u' + v}{1 + \frac{u'v}{c^2}}\right) = \left(\frac{0.932\text{c} + 0.271\text{c}}{1 + \frac{0.932\text{c} \times 0.271\text{c}}{c^2}}\right)$;

$u = 0.960\text{c}$; ***[2]***

*Award **[2]** for a bald correct answer.*

Allow working which does not mention c.

17. (a) it is impossible to distinguish gravitational effects from effects of acceleration/ inertial effects;
a frame of reference accelerating in (outer space) is equivalent to a frame at rest in a gravitational field;
a frame of reference in free fall in a g-field is equivalent to a frame moving at constant velocity in outer space; ***[1 max]***
Make careful use of OWTTE in this question.
Do not accept vague statement such as "gravity and acceleration are the same".

(b) (i) the box is equivalent to an inertial frame of reference (far from any masses);
so $f_C = f_0$; ***[2]***

(ii) the energy of a photon is hf_P;
light loses energy as it rises;
so $f_P < f_0$; ***[3]***

or

P's frame of reference is equivalent to a frame accelerating upwards (far from any masses);
P moves away from the emitted light / the "space" between P and original source increases;
so (by the Doppler effect) $f_P < f_0$;

(c) the mass of the Sun bends the spacetime around it;
particles follow paths of least length/geodesics (when no forces act on them);
paths of least length/geodesics are curves in the bent spacetime; ***[2 max]***

Option I — Medical physics

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

(b) (i) $I = \dfrac{25}{4\pi[4.5]^2}$;

$I = 9.8 \times 10^{-2}\left(\text{Wm}^{-2}\right)$;

$IL = 10\lg\left[\dfrac{9.8 \times 10^{-2}}{1 \times 10^{-12}}\right](=109.9\,\text{dB})$;

$(=110\,\text{dB})$ ***[3]***

Answer is given, award marks for correct working only.
ECF still applies even if final answer is wrong.

(ii) temporary/permanent deafness;
tinnitus / ringing in the ears / *OWTTE*;
selective frequency losses / loss of frequency range;
damage to inner/outer ear; ***[2 max]***

19. (a) X-ray images taken of a slice/section (through body);
from many different angles/directions;
repeated for successive slices/sections;
images are combined using computer (graphics);
to form a 3D image;
that can be rotated/viewed from different angles; ***[5 max]***

(b) greater exposure / greater absorbed dose / more expensive / more harmful; ***[1]***
Do not accept "takes longer".

(c) $\mu = \dfrac{\ln 2}{1.2}\left(= 0.58\,\text{cm}^{-1}\right)$;

$0.15 = e^{-0.58x}$;

$x = 3.3\,\text{(cm)}$; ***[3]***

*Award **[3]** for a bald correct answer.*
Watch for valid working in metres.

or

$(0.5)^n = 0.15$ (where n is number of half value thicknesses travelled);
so $n = 2.74$;
$x = (2.74 \times 1.2\,\text{cm} =)\,3.3\,\text{(cm)}$;
*Award **[3]** for a bald correct answer.*

20. (a) product of density of the substance and the speed of <u>sound</u> in that substance; ***[1]***

(b) (i) $c = \left(\frac{1.70\times10^6}{1.08\times10^3} =\right) 1570\,(\mathrm{m\,s^{-1}})$; ***[1]***

(ii) read-off to yield time of 40×10^{-6} (s) ;
travel time $= 20\times10^{-6}$ (s) ;
thickness $= \left(1570\times\frac{40\times10^{-6}}{2} =\right) 3.1$ (cm) ***or*** 3.2 (cm); ***[3]***
*Award **[3]** for a bald correct answer.*
*Award **[2 max]** for answer of 6.2 (cm) or 6.3 (cm).*

(c) *advantage*: greater penetration / less attenuation / can scan organs at greater depth;
disadvantage: less resolution / image has less detail / image less sharp; ***[2]***

21. (a) energy absorbed per unit mass; ***[1]***
*Award **[0]** for reference to energy or mass of a particle.*

(b) (i) energy received by tumour $= (55\times15\times10^{-3} =)\ 0.825$ (J);
number of beta particles emitted $= \left(\frac{0.825}{6.0\times10^5\times1.6\times10^{-19}} =\right) 8.59\times10^{12}$;
average activity $= \left(\frac{8.59\times10^{12}}{5\times24\times60\times60} =\right) 2.0\times10^7$ (Bq) ; ***[3]***
Watch for ECF.
*Award **[3]** for a bald correct answer.*

(ii) keep source in shielded container when not used;
minimize the time handling the source;
film badge monitoring;
wear protective clothing;
increase distance from source; ***[1 max]***

(c) (i) source with half-life of 75 days (is most suitable);
activity remains (approximately) constant (to give correct absorbed dose); ***[2]***

(ii) less radiation received by whole body / fewer healthy cells subjected to radiation / damage localized to the tumour; ***[1]***

Option J — Particle physics

22. (a) (i) kaons are bosons/mesons and have integral spin;
the Pauli exclusion principle only applies to fermions not bosons/applies to half-integral spin particles; ***[2]***

(ii) free quarks cannot be produced (quark/colour confinement);
as energy is supplied the separation of the quarks increases;
eventually a new meson/baryon will be produced / formation of quark – anti uark pair with colour – anti colour; ***[3]***

(b) (i) the decay does not conserve strangeness;
and only the weak interaction violates strangeness conservation; ***[2]***

or

a neutrino is produced in this decay;
neutrinos interact only via the weak interaction;

(ii) $R = \left(\frac{h}{4\pi mc} = \right)\frac{6.63\times10^{-34}\times3\times10^{8}}{4\pi\times\left[80\times10^{9}\times1.6\times10^{-19}\right]}$;

$R = 1.2\times10^{-18}\,(\text{m})$; ***[2]***

No ECF if wrong value for m is used.

(c) does not conserve baryon/quark/lepton number; ***[1]***

23. (a) (i) total minimum energy required is $2\times173 = 346\,(\text{GeV})$;
and so the kinetic energy required is $346 - 2\times0.938 = 344$ (GeV) ***or*** $5.5\times10^{-8}\,(\text{J})$; ***[2]***
*Award **[2]** for a bald correct answer.*
*Award **[1 max]** for use of one quark, giving an answer of 171 (GeV).*

(ii) available energy must be $2\times173 = 346\,(\text{GeV})$;
$346^2 = 2(0.938)E + 2\times0.938^2$;
giving $E = 6.4\times10^{4}\,(\text{GeV})$ ***or*** $1.0\times10^{-5}\,(\text{J})$; ***[3]***
*Award **[3]** for a bald correct answer.*
*Award **[2 max]** if only one t quark is used. Gives 1.6×10^{4} (GeV).*

(iii) *advantage*:
achieve higher energies / collision times can be controlled;

disadvantage:
complex/expensive machines / low probability of collisions / a very large proportion of the energy is lost in synchrotron radiation; ***[2]***

(b) a chamber of gas contains a grid of charged wires;
charged particles produce ionization in the gas;
electrons and ions drift to/produce a current in the charged wires;
the ion drift speeds/arrival times are measured;
the position/path/energy of the charged particles may be determined; ***[3 max]***
Accept marking points in the form of a labelled diagram.

24. (a) (scattering experiments in which) high energy leptons/electrons/muons/neutrinos are fired at hadrons/nucleons;
(scattering experiments in which) large amounts of energy and momentum are transferred to a hadron; ***[1 max]***
To award the mark some reference to high energy is necessary.

(b) (i) the experiments measure the amount of the momentum of a hadron carried by charged constituents/quarks;
momentum is less than expected indicating the presence of electrically neutral constituents/gluons; ***[2]***

(ii) the scattering data (from the electromagnetic interaction with a quark inside a hadron) interpreted in terms of Feynman diagrams;
confirms that each quark comes in three types which is evidence for colour; ***[2]***

25. (a) $\frac{3}{2}kT = 2m_e c^2 \Rightarrow T = \frac{4m_e c^2}{3k}$ ***or*** $\frac{4\times 9.11\times 10^{-31}\times\left[3\times 10^{8}\right]^{2}}{3\times 1.38\times 10^{-23}}$;
$T = 7.9\times 10^{9}$ (K); ***[2]***
Award ***[1 max]*** *for an answer of* 4×10^{9} *(K) for use of single electron mass.*

(b) as the universe expanded / cooled down;
photons could no longer create particle–antiparticle pairs;
particles continued to annihilate antiparticles;
leaving behind the small excess of particles over antiparticles that existed in the very early universe; ***[3 max]***