Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

November 2015

Physics

Higher level

Paper 3

17 pages

International Baccalaureate
Baccalauréat International
Bachillerato Internacional

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.

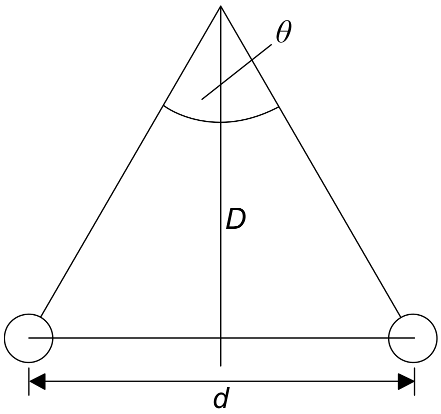
5. Words that are underlined are essential for the mark.

6. The order of marking points does not have to be as in the markscheme, unless stated otherwise.

Option E — Astrophysics

1. (a) the star is (much) closer than the other star (and close enough to Earth) / parallax effect has been observed; **[1]**

(b) (i)



[1]

*Award **[1]** if all three (d, D, θ) are shown correctly.*
Accept D as a line from Earth to the star.

(ii) $\sin\frac{\theta}{2} = \frac{d}{2D}$ ***or*** $\tan\frac{\theta}{2} = \frac{d}{2D}$ ***or*** $\theta = \frac{d}{D}$;

consistent explanation, *eg*: small angle of approximation yields $\theta = \frac{d}{D}$; **[2]**

(iii) any angular unit quoted for θ and any linear unit quoted for *D*; **[1]**

(c) this star is less than 1000 pc away/in our galaxy;
Hubble's law is for galaxies (not local stars) / red-shift will be too small to measure / uncertainty in Hubble constant high for such measurement; **[2]**

2. (a) HR diagram refers to real stars / absolute magnitude depends on (inherent) properties of the star / absolute magnitude is a measure of brightness at a distance of 10 pc;
any relevant info about apparent magnitude, *eg*: apparent magnitude depends on distance; **[2]**

(b) to cover a wide range of orders of magnitude;
smaller values would be lost on a linear scale / the logarithmic scale allows more stars to be shown on the diagram (making the diagram more relevant); **[2]**

(c) $\frac{L_V}{L_S} = \left(\frac{\sigma A_V [T_V]^4}{\sigma A_S [T_S]^4} = \right) \frac{\sigma [r_V]^2 [T_V]^4}{\sigma [r_S]^2 [T_S]^4}$;

$\frac{1.54 \times 10^{28}}{3.85 \times 10^{26}} = \frac{[r_V]^2}{[r_S]^2} \times \frac{9600^4}{5800^4}$;

$r_V = \left(\sqrt{\frac{1.54 \times 10^{28}}{3.85 \times 10^{26}} \times \frac{5800^4}{9600^4}} r_S = \right) 2.3\, r_S$; **[3]**

(d) obtain the spectrum of the star;
measure the position of the wavelength corresponding to maximum intensity;
use Wien's law (to determine temperature); } *(allow quotation of Wien's equation if symbols defined)* **[3]**

Award ***[3 max]*** *for referring to identification of temperature via different ionizations of different elements.*

(e) (i) insufficient hydrogen (to continue fusion);
star collapses (under gravity);
temperature increases;
initiated fusion of helium, (energy released causes) rapid expansion of star; **[4]**

(ii) rapid expansion / increase of size;
decrease in temperature / cooler stars appear red in colour / increase of luminosity; **[2]**

3. (a) (i) $T = \frac{2.90 \times 10^{-3}}{\lambda_{max}} = \frac{2.90 \times 10^{-3}}{1.06 \times 10^{-3}}$;
$= 2.7\,\mathrm{K}$; **[2]**

(ii) current low temperature observed is a result of expansion;
(expansion) has caused cooling from high temperatures; **[2]**

(b) (i) $\left(\frac{\Delta\lambda}{\lambda} = \frac{v}{c} \Rightarrow \right) v = \left(\frac{3.00 \times 10^8 \times 74}{656} = \right) 3.38 \times 10^7\,(\mathrm{m\,s^{-1}})$;

$d = \frac{v}{H_0} = \frac{3.38 \times 10^4}{69.3} = 488\ \mathrm{Mpc}$; **[2]**

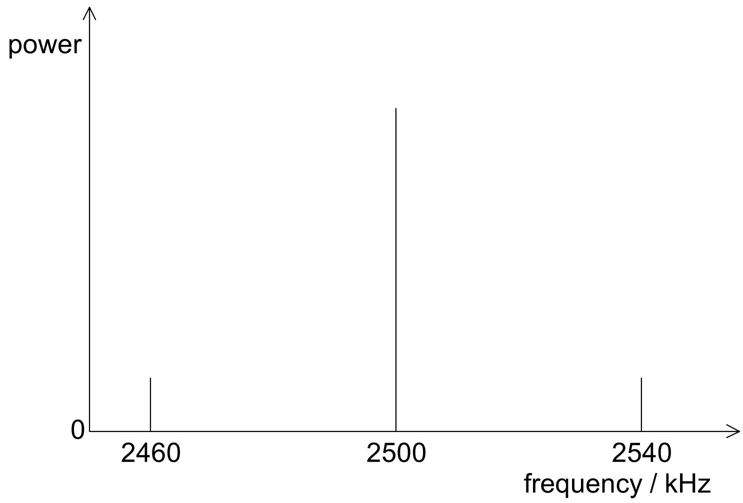
(ii) measurements from distant galaxies have large uncertainties; **[1]**

Option F — Communications

4. (a) the modification/change of a carrier wave by addition of a signal wave/information; **[1]**

(b) (i) (voice signal only requires) low quality;
AM has lower band width requirement than FM;
simpler (more reliable) circuits;
range greater than FM / can bounce off the ionosphere; **[2 max]**

(ii)



central band drawn at correct position;
shorter side bands at correct positions; **[2]**

(iii) $\left(\frac{0.4\times10^6}{80\times10^3}=\right)5$; **[1]**

(iv) damage caused by mining for precious metals;
high rate of disposal/landfill;
masts detract from beauty in some areas; **[2 max]**

(c) *geostationary*: **[2 max]**

Allow ***one*** *advantage plus argument*:
always above the same point of the Earth / no tracking dish required / allows for continuous communication / outside Earth's atmosphere so last longer in orbit / can be positioned permanently in sunlight for its power supply;
evidence of the mentioned / any relevant argument;

or

Allow any ***two*** *advantages*:
always above the same point of the Earth;
no tracking dish required;
allows for continuous communication;
outside Earth's atmosphere so last longer in orbit;
can be positioned permanently in sunlight for its power supply;

polar-orbiting: **[2 max]**

Allow ***one*** *advantage plus argument*:
lower orbit / less power required at both ground station and satellite / cheaper to put into orbit / coverage of whole planet over a number of orbits;
evidence of the mentioned / any relevant argument;

or

Allow any ***two*** *advantages*:
lower orbit;
less power required at both ground station and satellite;
cheaper to put into orbit;
coverage of whole planet over a number of orbits; **[4 max]**

5. (a) (i) (a digital) signal is split up for transmission and recombined at the end of the process / the signal is transmitted in pulses;
other signals can be transmitted in the spaces between the pulses; **[2]**

(ii) the bit rate is higher / more data sent per unit time;
faster transmission of data;
making use of empty space between samples; **[1 max]**

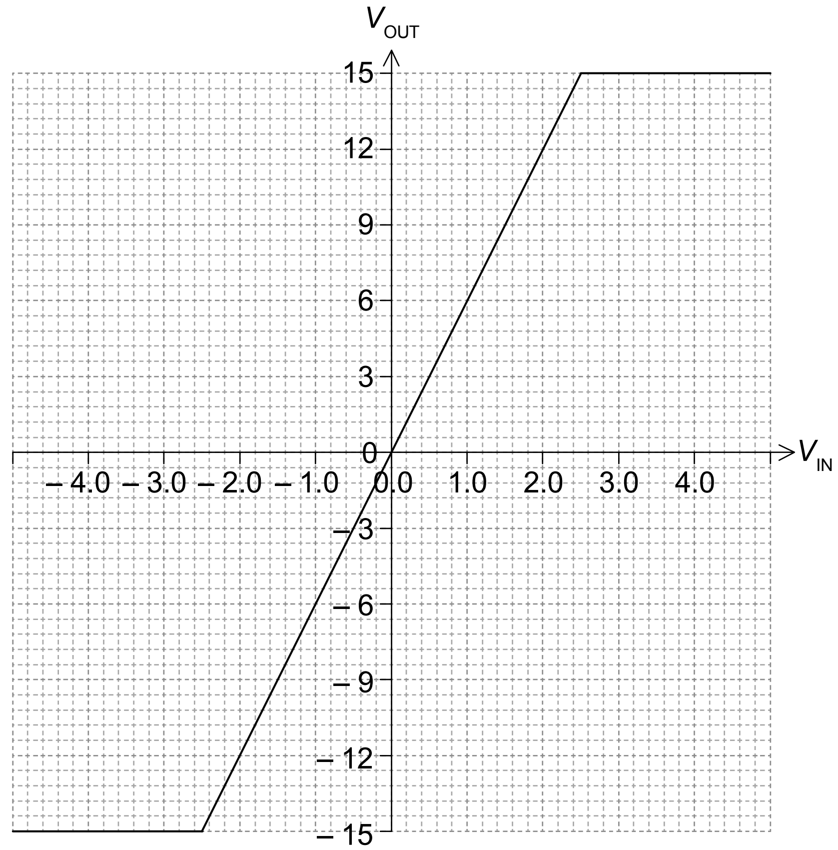
(b) time between samples $= \frac{1}{4000} = 250\ \mu s$;
duration of sample $= 8\text{ bit} \times 8\ \mu s = 64\ \mu s$;
number of samples transmitted $= \frac{250}{64} = 3.9$ signals;
so three signals maximum; **[4]**

(c) attenuation $= 0.08 \times 30.0\ (= 2.4\ \text{dB})$;
$2.4 = 10\log\left(\frac{I_1}{2\ \text{mW}}\right)$;
$I_1 = 3.5\ \text{mW}$; **[3]**

6. (a) (i) $G = 1 + \frac{20}{4}$;

$= 6$; **[2]**

(ii)



general shape of graph correct;
straight line between –2.5 V and 2.5 V;
plateau at –15 V and +15 V beyond this; **[3]**

(b) switch over happens when non-inverting input $\geq 5\,\text{V}$;

current through the $20\,\text{k}\Omega = \left(\frac{5-(-15)}{20 \times 10^3} = \frac{20}{20 \times 10^3} = \right) 1\,\text{mA}$;

$V_{IN} = (5 + [1\,\text{mA} \times 4\,\text{k}\Omega] = 5 + 4 =)\ 9\,\text{V}$; **[3]**

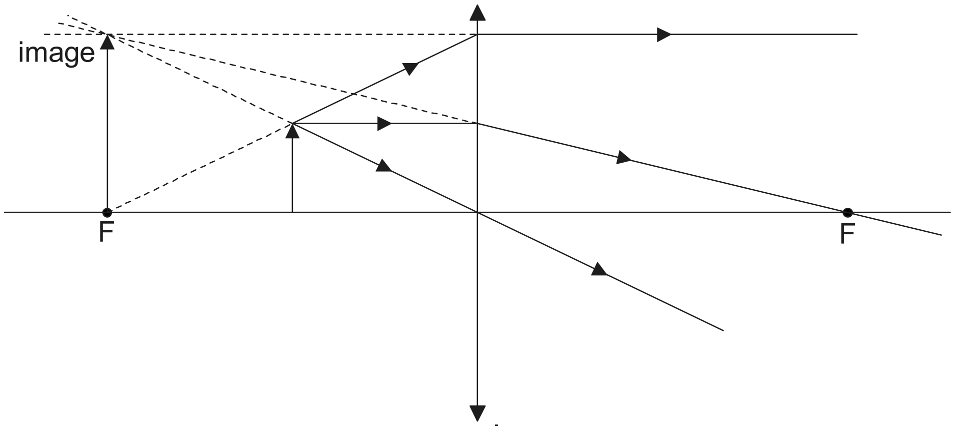
Option G — Electromagnetic waves

7. (a) sky is blue due to scattering of light from Sun (by particles, nitrogen molecules);
blue scatters better / as the atmosphere (becomes) less dense less scattering occurs;
(finally) the sun's light is not scattered and "the sky" is black (meaning no light between point light sources); **[3]**

(b) natural frequency of carbon dioxide $= \left(\frac{1}{5\times10^{-14}} =\right) 2\times10^{13}\text{ Hz}$;

infrared from the Sun is well outside this value so transmitted;
infrared from the Earth is close to this value so absorbed/scattered/trapped; **[3]**

8. (a) (i)



any correct ray out of the three shown above;
second ray correct;
image correctly located and labelled; **[3]**

(ii) the image is virtual;
no light rays pass through this point; **[2]**

(b) $\frac{1}{u} = \frac{1}{f} - \frac{1}{v}$;

$u = \frac{20}{3}$;

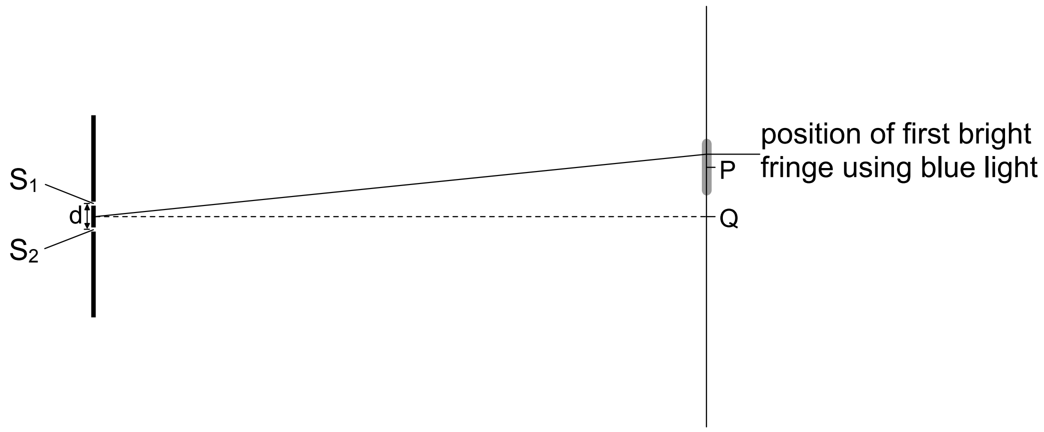
$m = \left(-\frac{v}{u} = -\frac{60}{20} =\right)(-)3$; **[3]**

9. (a) single slit before the double slit / use a laser light / single source; **[1]**

(b) destructive interference;
path lengths from slits differ by half a wavelength;
waves arrive antiphase / 180° out of phase / π out of phase; **[2 max]**

(c) (i) $\theta_{\text{blue}} = \left(\frac{\theta_{\text{red}} \lambda_{\text{blue}}}{\lambda_{\text{red}}} = \frac{0.0045 \times 440\,\text{nm}}{660\,\text{nm}} = \right) 0.0030\,\text{rad}$;
$\Delta\theta_{\text{blue}} = (0.0045 - 0.0030 =)\ 0.0015\,\text{rad}$; **[2]**

(ii) marking direction of shift on the diagram; **[1]**



10. (a) $\lambda_{\text{min}} = \left(\frac{hc}{eV} = \frac{6.63 \times 10^{-34} \times c}{1.6 \times 10^{-19} \times 50 \times 10^{3}} = \right) 8.29 \times 10^{-20}\,c$ ***or*** $2.49 \times 10^{-11}\,\text{m}$;
$f_{\text{max}} = \left(\frac{c}{\lambda_{\text{min}}} = \frac{c}{8.29 \times 10^{-20}\,c} = \right) 1.2 \times 10^{19}\,\text{Hz}$; **[2]**

(b) (i) continuous distribution component (Bremsstrahlung) extending to higher frequencies;
sharp peaks in the same position; **[2]**

(ii) incident electrons have higher energy so if one photon emitted it will have a higher frequency;
the characteristic line components/peaks depend on the target, as target does not change, positions do not change;
(if there are more incident electrons/current and) electrons have more energy so the area under the curve must be higher; **[2 max]**

11. (a) $\lambda' = \frac{\lambda}{1.33} = \frac{572}{1.3} = 440\,\text{nm}$; **[1]**

(b) 110 nm; **[1]**

(c) there would be a full wavelength within the film;
but the phase change at the first surface means that there is always destructive interference; **[2]**

Option H — Relativity

12. (a) a coordinate system;
that is not accelerating / where Newton's first law applies; **[2]**

(b) (i) $\gamma = \left[\frac{1}{\sqrt{1-0.8^2}} =\right] 1.67$;

$\Delta t_0 = \left[\frac{3}{1.67} =\right] 1.8\text{ s}$; **[2]**

(ii) $u_x{}' = \frac{0.8c - [-0.8]c}{1+0.8^2} (= 0.976c)$;

$\gamma = \frac{1}{\sqrt{1-0.976^2}} (= 4.56)$;

$l_0 = (4.56 \times 8.0 =) 36\text{ m}$; **[3]**

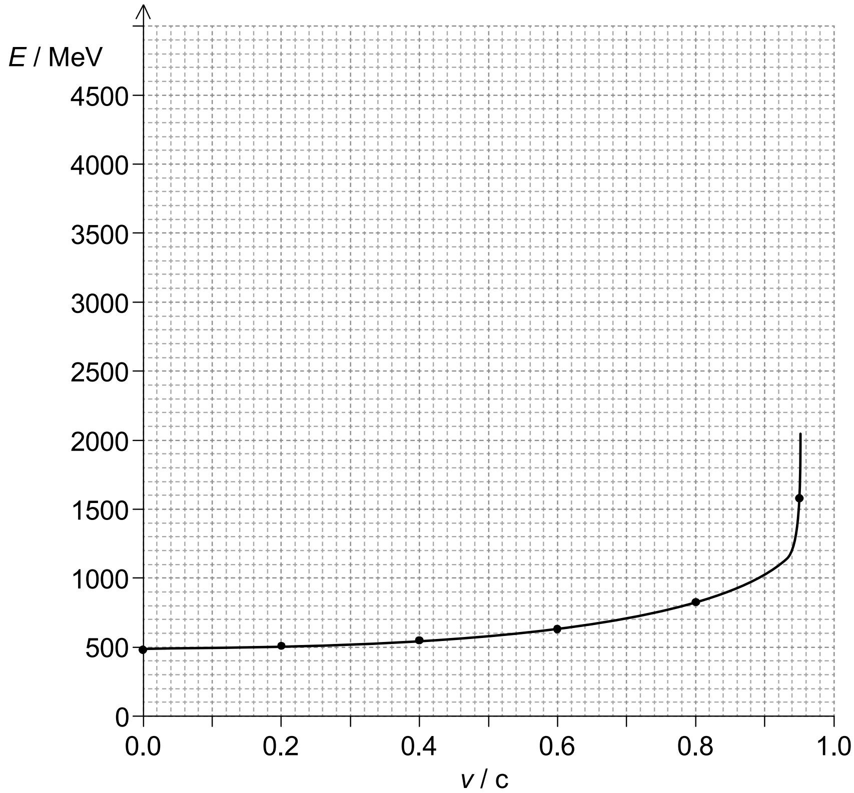
(c) (i) $t = \frac{s}{v} = \frac{11.4}{0.8} =$ 14.25 years;

$\Delta t_0 = \frac{\Delta t}{\gamma} = \frac{14.25}{1.67} = 8.6$ years; **[2]**

Accept length contraction with the same result.

(ii) situation is not symmetrical;
Suzanne must undergo acceleration (when changing direction) but Juan does not; **[2]**

13. (a) (i)



graph starting at $E = 494$ when $\frac{v}{c} = 0$ ***or*** a roughly horizontal line drawn until at least 0.4 c;

rises sharply/becomes asymptotic as $\frac{v}{c}$ approaches 1; **[2]**

(ii) $E_K = 2 \times 494\text{ MeV} = 988\text{ MeV}$;

potential difference $= 988 \times 10^6$ V ***or*** 1×10^9 V; **[2]**

(b) $pc = \left(\sqrt{\left[\frac{E}{2}\right]^2 - m_0^2c^4} = \right)\sqrt{\left[\frac{498}{2}\right]^2 - 135^2}$;

$p = 209\text{ MeV c}^{-1}$; **[2]**

14. (a) (according to a Galilean transformation) speed of light depends on the direction of motion (through the ether);
beam which reflects from mirror M_1 takes different/less time than the beam reflecting from M_2;
the time taken to travel each path will change as the apparatus is rotated;
a changing interference pattern is observed; **[4]**

(b) there was no change (in the interference pattern observed); **[1]**

(c) the speed of light doesn't depend on motion (through the ether) / there is no ether;
the speed of light (in a vacuum) is the same for all inertial observers; **[2]**

15. (a) (i) $\frac{3.20}{4.52 \times 10^{14}} = \frac{g \times 112}{c^2}$;

$g = 5.69\,\text{N kg}^{-1}$; **[2]**

(ii) as photon moves away from the surface of the planet it gains gravitational potential energy;
$E = hf$ the frequency has become lower (to compensate for this change); **[2]**

(b) the equivalence principle states that it is impossible to distinguish between an accelerating reference frame and a gravitational field;
therefore the frequency observed will be the same; **[2]**
Accept combined effect if spacecraft still in the gravitational field.

Option I — Medical physics

16. (a) hearing loss at all frequencies;
most marked between 1–4 kHz / higher frequencies; **[2]**

(b) (i) minimum intensity audible to an average person;
of a pure tone / at 1000 Hz; **[2]**

(ii) $IL = 32\text{ dB}$; *(accept answers in the range of 31 to 33 dB)*

$32 = 10\log\left(\frac{I}{1.0\times10^{-12}}\right)$;

$I = 1.6\times10^{-9}\text{ W m}^{-2}$; **[3]**

Final answer could range from 1.3×10^{-9} *to* 2.0×10^{-9} *depending on the value chosen for the first marking point.*

(c) embarrassment/frustration/misinterpretation; *(allow other valid suggestions)*
potential limitations of employment (some roles cannot be fulfilled) / cost of hearing aid technology; *(allow other valid economic implications)* **[2]**

17. (a) *physical half-life*:
is time for activity of a radioactive sample to drop to a half due to nuclear decay;

biological half-life:
is the time for amount of a substance in the body to drop to a half due to physiological/biological processes; **[2]**

(b) (in six days three physical half-lives elapse, so $\frac{1}{2}\times\frac{1}{2}\times\frac{1}{2}=)\frac{1}{8}$ remains in body;

(two biological half-lives elapse, so activity drops to $\frac{1}{2}\times\frac{1}{2}=)\frac{1}{4}$ remains in body;

(so activity remaining in body is) $\frac{1}{8}\times\frac{1}{4}$ ***or*** $\frac{1}{32}$ ***or*** 0.031 of original activity; **[3]**

OR

$\frac{1}{T_E}=\left(\frac{1}{T_P}+\frac{1}{T_B}=\frac{1}{2.0}+\frac{1}{3.0}=\right)\frac{5}{6}$;

$T_E = 1.2$ (days);

(in 6.0 days there are 5 half-lives), so fraction remaining is $\left[\frac{1}{2}\right]^5=\frac{1}{32}$ ***or*** 0.031;

(c) radiation from the tracer must be measurable (and ideally fairly constant);
thus reduction in activity largely comes from biological processes; **[2]**

18. (a) (i) product of the density of a substance and the speed of sound in that substance; **[1]**

(ii) if impedance is not matched, large percentage of energy loss at interface;
difference in acoustic impedances necessary for imagery/reflection from organs; **[1 max]**

(b) attenuation increases with frequency / deeper objects require lower frequencies;
resolution increases with frequency;
balance required between energy loss/attenuation and image quality/resolution; **[3]**

19. (a) the thickness which will reduce the intensity of the radiation to a half; **[1]**

(b) general exponential decay shape drawn;
value approximately halves at 3, 6, and 9 cm;
I intercept shown, becoming asymptotic on *t*-axis; **[3]**

(c) (i) $\frac{I_0}{2} = I_0 e^{-\mu x_{\frac{1}{2}}}$;

$0.5 = e^{-\mu x_{\frac{1}{2}}}$ ***or*** $\ln I_0 + \ln 0.5 = \ln I_0 - \mu x_{\frac{1}{2}}$;

$x_{\frac{1}{2}} = \frac{\ln(2)}{\mu}$; **[3]**

No mark for copying equation from question.

(ii) 0.23;
cm^{-1}; **[2]**

OR

23;
m^{-1};

Option J — Particle physics

20. (a) $+\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$ for charge;
any particle containing a strange quark has strangeness of -1; **[2]**

(b) (i) *strangeness*:
the p has a strangeness of 0;
the K^- particle has a strangeness of -1;

baryon number:
lambda and protons are baryons each having a baryon number of $+1$;
the K^- meson has a baryon number of 0; **[4]**

(ii) only during the weak interaction strangeness is not conserved (therefore it is a weak interaction); **[1]**

(iii) $m=\left[80.4\,\text{GeV}\,\text{c}^{-2}=\frac{80.4\times10^{9}}{931.5\times10^{6}}\times1.661\times10^{-27}=\right]1.43\times10^{-25}\,\text{kg}$;

$R\approx\left(\frac{6.63\times10^{-34}}{4\pi\times1.43\times10^{-25}\times3\times10^{8}}=\right)1.23\times10^{-18}\,\text{m}$; **[2]**

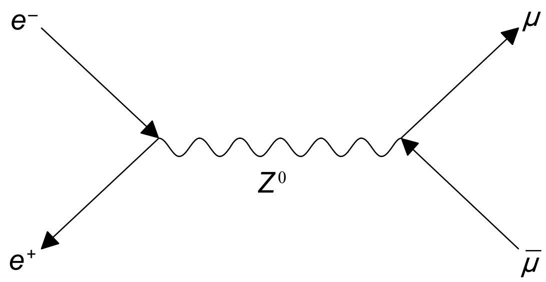
21. (a) *electric field*:
cyclotron: electric field alternates every half rotation of the particle;
synchrotron: high frequency electric field synchronized with particle speed;

magnetic field:
cyclotron: constant magnetic field;
synchrotron: magnetic field increases with particle speed; **[4]**

(b) mass of lead $=207\times931.5=193\,\text{GeV}\,\text{c}^{-2}$;
$E_a^2=2\times193\times575\times10^{3}+2[193]^{2}=2.22\times10^{8}$;
$E_a=14.9\,\text{TeV}$; **[3]**

22. (a) (i) a particle that mediates one of fundamental forces / a particle that appears as an intermediate particle in a Feynman diagram / a particle that is not observed and may violate energy and momentum conservation at a vertex; **[1]**

(ii)



electron and positron directions and symbols shown correctly;
muon and antimuon directions and symbols shown correctly; **[2]**

(iii) Z^0 boson, no charge has been transferred/neutral current; **[1]**

(b) the discovery would help to verify standard model;
the Higgs is responsible for giving mass to particles / is linked to the problem of mass; **[2]**

23. (a) very high potential differences produce very high (kinetic) energies;
high energy electrons have a very short wavelength;
the wavelength of the electron is small enough to interact with the particles inside the proton; **[3]**

(b) the strong force decreases as the energy increases;
(at high energies) the electron appears to scatter off individual quarks; **[2]**

24. (a) $0.1\times10^{6}\times1.6\times10^{-19}=\frac{3}{2}\times1.38\times10^{-23}\times T$;
$T=7.7\times10^{8}\,\text{K}$; **[2]**

(b) (although the average energy of the particles is low) some pairs of particles may still have sufficient energy; **[1]**