International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

MARKSCHEME

May 2010

PHYSICS

Higher Level

Paper 3

16 pages

General Marking Instructions

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. Do **not** award more than the maximum marks allowed for part of a question.

2. Each marking point has a separate line and the end is signified 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 writing ***OWTTE*** (or words to that effect).

8. 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.

9. Only consider units at the end of a calculation. Unless directed otherwise in the markscheme, unit errors should only be penalized once in the paper.

10. Significant digits should only be considered in the final answer. Deduct **1 mark in the paper** for an **error of 2 or more digits** unless directed otherwise in the markscheme.

e.g. if the answer is 1.63:

2	*reject*
1.6	accept
1.63	accept
1.631	accept
1.6314	*reject*

Option E — Astrophysics

E1. (a) *stars*: $\frac{75}{4.19(17)^3} = 3.6\times10^{-3}\,(\text{ly}^{-3})$;

galaxies: $\frac{26}{4.19\ \ 4.0\times10^6\ ^3} = 9.7\times10^{-20}\,(\text{ly}^{-3})$; *[2]*

*Award **[1 max]** if the response does not use the volume of the sphere but uses the cube instead.*

(b) $\frac{10^{-3}}{10^{-19}} = (3.8\times)10^{16}$ ***or*** star population density greater than galaxies population density by an order of magnitude 16; *[1]*

E2. (a) (i) luminosity is a function of surface and temperature (of star);
(same class) same temperature (therefore greater surface area); *[2]*

(ii) $L_C = 80\,L_S$; *(accept answer in the range of 60 to 100)* *[1]*

(iii) $\frac{L_C}{L_S} = \left[\frac{r_C}{r_S}\right]^2 = 80$;

$r_C^2 = 80 r_S^2 \Rightarrow r_C = 8.9 r_S$; *[2]*

(b) (i) 0.6; *(accept answer in the range of 0.4 to 0.8)* *[1]*

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

$0.0 - 0.6 = 5\log\frac{d}{10}$;

$\frac{d}{10} = 10^{-0.12}$;

$d = 7.6\,\text{pc}$; *[3]*

(iii) Vega appears dimmer;
hence distance over-estimated; *[2]*

accept:
Vega will look redder (because blue light scatters more in dust);
so Vega looks cooler/lower apparent temperature (thus wrong position on HR diagram);

E3. (a) (Big Bang theory predicts that CMB will) correspond to the black-body at $3\,\text{K}$;
the graph is of a black-body curve;
$T = \dfrac{2.9\times10^{-3}}{10^{-3}} \approx 3\,\text{K}$; *[3]*

(b) measurement of mass in a given volume is (very) uncertain/difficult;
there exists dark matter that is difficult to observe;
measurement of distances is uncertain/difficult;
matter not uniformly distributed; ***[2 max]***

(c) in the early universe the (average) kinetic energy was very high breaking apart any nuclei/atoms/too high for atoms to form / as universe expands it cools down allowing nuclei in atoms to form; *[1]*

E4. (a) (using mass–luminosity relation for main sequence)
$\dfrac{L}{1} = \left[\dfrac{25}{1}\right]^{3.5} = 7.8\times10^{4} \approx 8\times10^{4}$; *[2]*
therefore, star obeys mass–luminosity relation and therefore main sequence;

or

$8\times10^{4} = 25^{\text{n}}$;
$\log\left[8.4\times10^{4}\right] = \text{n}\log 25$
$\text{n} = 3.5$
therefore star obeys mass–luminosity relation and therefore main sequence;

(b) $\text{MS} \rightarrow$ supergiant;
supernova explosion leaving behind core;
core becomes black hole <u>or</u> neutron star depending on Oppenheimer–Volkoff limit / black hole because the Oppenheimer–Volkoff limit is exceeded / neutron star because below the Oppenheimer–Volkoff limit; *[3]*

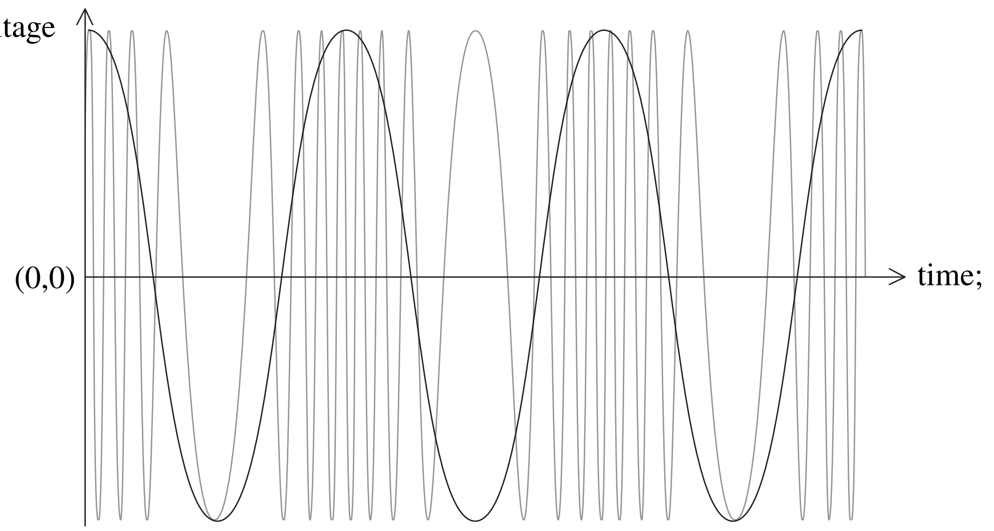
E5. (a) $v = \dfrac{\Delta\lambda}{\lambda}c = \dfrac{5.04}{396.8}\ 3\times10^{8}$;
$v = 3.81\times10^{6}\,\text{m}\,\text{s}^{-1}$ / $1.27\times10^{-2}\,\text{c}$; *[2]*

(b) (i) Cepheids / Supernovae; *[1]*

(ii) recognition of age = inverse of slope;
$= \dfrac{6.0\times10^{24}\,\text{m}}{15.9\times10^{6}\,\text{m}\,\text{s}^{-1}} (= 3.8\times10^{17}\,\text{s}) \approx 10^{17}\,\text{s}$; *[2]*

Option F — Communications

F1. (a)



[1]

Accept any signal with this frequency.

(b) FM has a better signal-to-noise ratio (than AM);
noise gets added to amplitude and since FM is modulated by frequency FM is less susceptible to noise; *[2]*

or

FM has a greater bandwidth (than AM);
and so provides for a better quality transmission;

or

in FM most of the power is in the sidebands (where the information is) rather than the carrier;
and so transmissions can take place at less power (than AM);

F2. (a) time between samples $= \frac{1}{8000} = 0.125\,\text{ms}$ ***or*** $0.13\,\text{ms}$;
duration of sample $4 \times 4.0 = 0.016\,\text{ms}$;
hence separation $= 0.125 - 0.016 = 0.109\,\text{ms}$ ***or*** $0.13 - 0.02 = 0.11\,\text{ms}$; *[3]*

(b) extra signals may be carried on the same transmission line;
in unused time on the transmission line in between samples; *[2]*

F3. *base stations*: ***[2 max]***
located at the centre of a cell receiving and transmitting radio signals from and to mobile phones;
communicates with the cellular exchange;
selects from the frequencies allotted to it by the cellular exchange for a particular call;

cellular exchange: ***[2 max]***
allows entry into the fixed telephone network;
allocates different frequencies to base stations;
in order to avoid interference between different calls;
reroutes calls to different base stations when a mobile phone leaves one cell area and enters another; ***[4 max]***

F4. (a) (i) Snell's law: $1.56 \times \sin\theta_C = 1.38 \times \sin 90^\circ$;

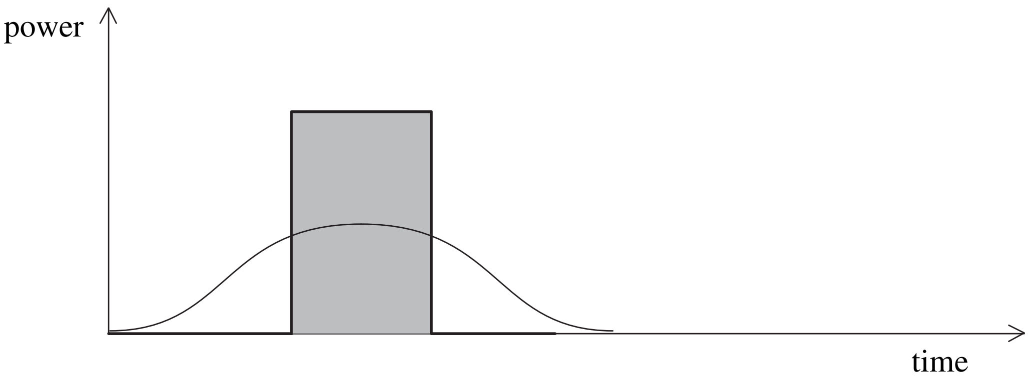
$\theta_C = \sin^{-1}\frac{1.38}{1.56} = 62.2^\circ$; ***[2]***

(ii) realization that angle of refraction in core is $90^\circ - 62.2^\circ$;
Snell's law: $1.00 \times \sin\theta_{max} = 1.56 \times \sin\left[90^\circ - 62.2^\circ\right]$;
to give $\theta_{max} = 46.7^\circ$ ***[2]***

(b) modal dispersion is dispersion due to rays of light taking different paths in the fibre;
material dispersion is dispersion due to the dependence of the speed of light on wavelength; ***[2]***

(c) (i) the total energy of the signal; ***[1]***

(ii)



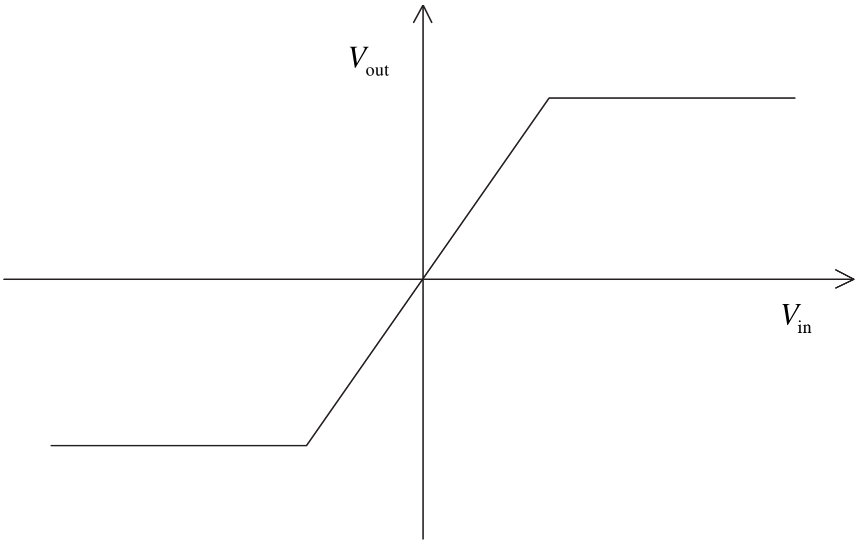
lower and wider;
with a curved (Gaussian-like) shape; ***[2]***
Accept the signal starting at any time position.

(iii) loss in dB is $1.24 \times 3.40 = 4.22\,\text{dB}$;

$-4.22 = 10\log\frac{P}{15.0}$;

so $P = 15.0 \times 10^{-0.422} = 5.68\,\text{mW}$; ***[3]***

F5. (a)



linear as shown;
saturation shown; ***[2]***

(b) (i) 0 V; ***[1]***

(ii) when the temperature rises above 50˚C the resistance of the thermistor falls below *R*;
and so the voltage at the non-inverting input of the op-amp is negative;
(the output voltage then saturates at –12 V) giving the required potential difference for the buzzer to sound; ***[3]***

Option G — Electromagnetic waves

G1. (a) *Look for these main points.*
(a metastable state *i.e.*) an excited state in which electrons stay (for unusually) longer times than in normal excited states;
population inversion (in which the number of electrons in a metastable state is larger than in the ground state);
stimulated emission in which an electron of the same energy as the difference in energy of atomic energy levels forces a transition from an excited state; ***[3]***
Mark generously as all of these points may be not expressed precisely.

(b) (the laser light is) monochromatic;
(and) coherent;
unidirectional/single beam; ***[2 max]***

G2. (a) (i) correct use of sign convention $\left(\frac{1}{20}=\frac{1}{24}+\frac{1}{v}\right)$;
$v = 120\,\text{mm}$; ***[2]***

(ii) real because $v > 0$ / image is formed by real rays (and not their extensions) / can be focused on a screen / rays are convergent; ***[1]***

(iii) correct use of sign convention $\left(\frac{1}{60}=-\frac{1}{240}+\frac{1}{u}\right)$;
$u = 48\,\text{mm}$; ***[2]***

(b) $M=\left[\frac{120}{24}\right]\times\left[\frac{240}{48}\right]$ ***or*** $M=\frac{120}{24}\times\left[\frac{240}{60}+1\right]$;
$M = 25$; ***[2]***
*Award **[1 max]** for answer of 20.*

G3. (a) (i) correct general shape with uniform spacing of maxima;
and equal intensity at maxima; ***[2]***
Accept a small reduction in amplitude if consistently shown from peak to subsequent peak.
*Award **[1 max]** if minima do not touch horizontal axis.*

(ii) $s = \left(\frac{\lambda D}{d} = \right)\frac{6.80\times10^{-7}\times1.40}{0.120\times10^{-3}}$;
$s = 7.93\,\text{mm}$; ***[2]***

(b) (i) pattern will be shifted horizontally such that the maxima and the minima are interchanged / *OWTTE*;
because the path difference has introduced a path length of $\frac{\lambda}{2}$ / phase difference of π ***or*** 180°; ***[2]***

(ii) no change;
since pattern has shifted by a constant amount; ***[2]***

G4. (a) correct shape of continuous part including cut-off wavelength;
presence of any characteristic lines; ***[2]***
Do not award second marking point if the peaks are clearly not vertical or if their width implies a large range of frequencies – judge by eye.

(b) continuous part is due to radiation emitted when electrons slow down as they strike the metal;
characteristic lines due to transitions inside target atoms;
after target atoms have been excited by electron collision; ***[3]***

(c) rearrangement to get $h = \frac{\lambda eV}{c}$;
$h = \frac{4.8\times10^{-11}\times1.6\times10^{-19}\times2.4\times10^{4}}{3.0\times10^{8}}$;
$h = 6.1\times10^{-34}\,\text{J s}$; ***[3]***

(d) $d = \frac{\lambda}{2\sin\theta}$ so $d = \frac{2.25\times10^{-10}}{2\sin 28.1^\circ}$;
$d = 2.39\times10^{-10}\,\text{m}$; ***[2]***
*Award **[1 max]** if the 2 is missing.*

Option H — Relativity

H1. (a) a coordinate system (used to record events) / a set of rulers and clocks (that may be used to record the position and time of events);
that is not accelerating / where Newton's first law applies; ***[2]***

(b) (i) $t' = 3.0 \times 10^{-5}$ s ;
$x' = 5.0 \times 10^{3} - 2.0 \times 10^{8} \times 3.0 \times 10^{-5} = -1.0 \times 10^{3}$ m ; ***[2]***

(ii) $u = \dfrac{u' + v}{1 + \dfrac{u'v}{c^2}}$;

$u = \dfrac{-c + v}{1 - \dfrac{v}{c}}$;

$u = -c$ ***[2]***

(c) neutral pions moving at close to the speed of light are observed to decay into two photons (in different directions);
the speed of each of the photons is measured to be *c* independently of the speed of the pion; ***[2]***

H2. (a) *proper length*:
is the length of an object in the object's rest frame / the length of the object as measured by an observer at rest relative to the object;

proper time interval:
is the time interval between two events taking place at the same point in space / the shortest time interval between two events; ***[2]***

(b) (i) realization that 6.00 s is the proper time;
so that time interval $= \gamma \times 6.00 = 7.50$ s ; ***[2]***

(ii) realization that 5.00 m is the proper length;
so that length $= \left(\dfrac{5.00}{\gamma} = \right) 4.00$ m ; ***[2]***
Do not apply SD deduction here.

(c) (i) laser B was fired first; ***[1]***

(ii) during the delay time *T*, space station moved backward a distance $vT = 6.25 - 4.00 = 2.25$ m ;
and so $T = \left(\dfrac{2.25}{0.600c} = \right) 1.25 \times 10^{-8}$ s ; ***[2]***

H3. $Mc^2 = 2E$;
$E = \sqrt{1.78^2 + 4.40^2} = 4.75\,\text{GeV}$;
so $M = 9.49$ ***or*** $9.50\,\text{GeV}\,\text{c}^{-2}$; ***[3]***

H4. (a) a frame of reference accelerating in outer space (with acceleration *a*) is equivalent to a frame of reference at rest in a (uniform) gravitational field (of field strength $g = a$); ***[1]***

or

an inertial frame of reference in outer space is equivalent to a freely falling frame of reference in a (uniform) gravitational field;

(b) there is relative motion between the observer at C and the beam of light / *OWTTE*;
and so by the Doppler effect the frequency at C will be less; ***[2]***

or

(by the equivalence principle) the rocket is equivalent to a similar rocket at rest in a gravitational field;
the photon moving towards C expends energy and so its frequency is reduced;

(c) A: curved path hitting below Y;
B: identical to A;
C: straight line hitting at Y; ***[3]***

(d) (i) the geometry of space does not follow the rules of planar/Euclidean geometry / light and particles (with no forces on them) follow geodesics that appear curved (in a background of ordinary flat space); ***[1]***

(ii) measurement of the position of a star during a solar eclipse as light from the star grazes/moves close to the Sun / *OWTTE*;
measurement of the position of the same star at night;
the two positions are different indicating that light has bent in the curved space around the Sun / *OWTTE*; ***[3]***
*Award **[3]** for a correctly labelled diagram.*

Option I — Medical physics

I1. (a) amplitude; *[1]*

(b) sound intensity level at 600 Hz is 16 dB;

$16 = 10\log\frac{I}{10^{-12}}$;

hence $I = 10^{-12} \times 10^{1.6} = 4.0 \times 10^{-11}\ \text{W m}^{-2}$; *[3]*

(c) (i) curve uniformly <u>above</u> given curve by 20 dB; *[1]*

(ii) frequency loss in frequency range commonly used in speech / harder to perceive sounds in the frequency range used for speech;
leading to difficulties with speech recognition / *OWTTE*; *[2]*

I2. (a) the product of the density of a medium times the speed of sound in the medium; *[1]*

(b) air and skin have very different (acoustic) impedance;
therefore a lot of the ultrasound gets reflected (rather than transmitted);
the impedance of the gel is close to that of skin;
and so very little ultrasound is reflected / most is transmitted; *[4]*

I3. (a) the distance that must be traversed such that the transmitted intensity is half the incident intensity / *OWTTE*; *[1]*

(b) (i) $x_{\frac{1}{2}} = 1.8\times10^{5}\times\dfrac{240}{2.0\times10^{4}}$;

$x_{\frac{1}{2}} = 2200\,\text{m}$; *[2]*

(ii) $I = I_0 e^{-\frac{\ln 2}{x_{\frac{1}{2}}}x}$;

$I = I_0 e^{-\frac{\ln 2}{2200}\times2.5\times10^{4}}$;

$\dfrac{I}{I_0} = 3.3$ ***or*** $= 3.8\times10^{-4}$; *[3]*

(c) yes, as the drop in X-ray intensity is very large; *[1]*

(d) (i) number of photons in body $2.8\times10^{8}\times1.6\times3\times3600 = 4.8\times10^{12}$;

energy of photons is $4.8\times10^{12}\times20\times10^{3}\times1.6\times10^{-19} = 0.0155\,(\text{J})$;

absorbed dose is then $\left(\dfrac{0.0155}{60}\right) = 2.6\times10^{-4}\,(\text{Gy})$;

dose equivalent $= 2.6\times10^{-4}\,\text{Sv}$; *[4]*

(ii) the passenger is protected by the plane walls/clothing / only part of the body gets irradiated; *[1]*

I4. (a) the time required for the body to get rid of half the radioactive nuclei in the body;
by the processes of both radioactive decay and natural bodily functions / *OWTTE*; *[2]*

(b) *advantage*:
the half-life is long enough;
for the investigation to be carried out;

disadvantage:
it decays by electron emission;
electrons will be absorbed by the body and so will do damage; *[4]*

Option J — Particle physics

J1. (a) (i) *meson*: $u\bar{d}$;
baryon: sss ; ***[2]***

(ii) 0 ***or*** 1 ***or*** –1; ***[1]***

(b) two identical fermions cannot occupy the same quantum state; ***[1]***

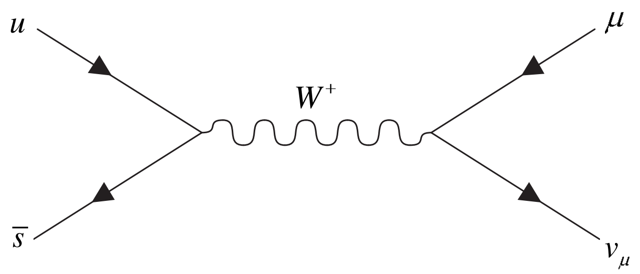
(c) (the three quarks are identical because they also have the same spin in this baryon and so) are distinguished by their three different colour quantum numbers; ***[1]***

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

(ii) blue-antired / blue-cyan; ***[1]***

(e) violates strangeness conservation which is a property of only the weak interaction; ***[1]***

(f)



correct topology as shown above, including arrows;
intermediate particle labelled as W^+;
other four particles $u, \bar{s}, \mu, \nu_\mu$ labelled at correct position; ***[3]***

J2. (a) they are neutral; ***[1]***

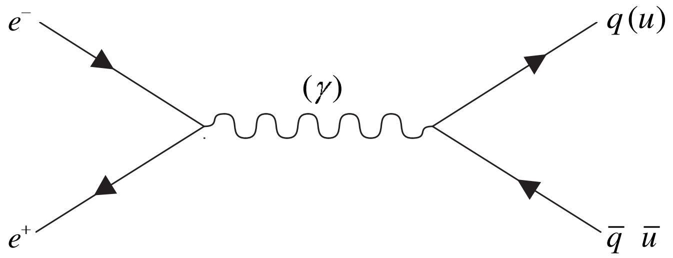
(b) (i) straight lines out of the "V's"; ***[1]***

(ii) where the lines drawn in (b)(i) intersect; ***[1]***

(c) it is moving;
because the photon paths are not opposite each other; ***[2]***
*Award **[0]** for correct answer without explanation or incorrect explanation.*

(d) it is colliding with molecules in the bubble chamber and losing energy; ***[1]***

J3. (a) (i)

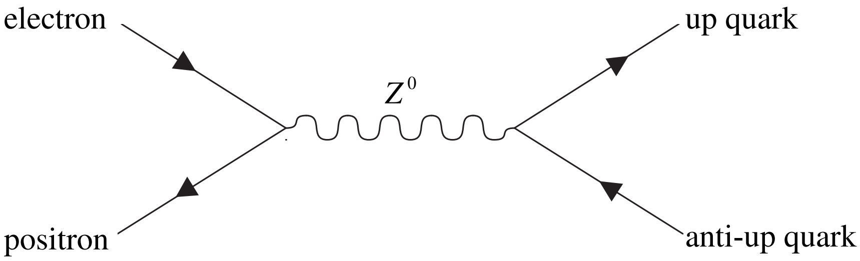


with particles correctly labelled and arrows correct; ***[1]***

(ii) quarks cannot appear as isolated particles due to confinement;
other quarks will be created out of the vacuum to form hadrons / *OWTTE*; ***[2]***

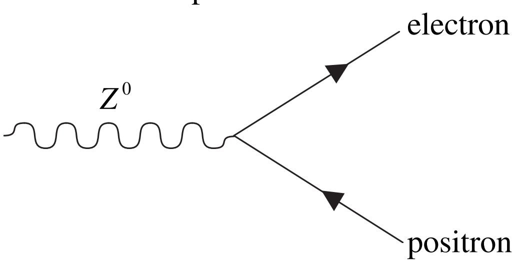
(b) (i) a process in which the intermediate particle is the Z^0 / a process involving Z^0 exchange; ***[1]***

(ii)



correct diagram as shown; ***[1]***

(c) the Z^0 can couple/interact with an electron and a positron according to



;

and so can be detected through its decay into an electron positron pair; ***[2]***

(d) generation lepton number must be conserved;
electron has electron lepton number $L_e = +1$;
and so it is an electron antineutrino (which has $L_e = -1$); ***[3]***

J4. the temperature of the (very) early universe was very high but started to fall as the universe expanded;
photons thus had a lot of energy to excite/ionize hydrogen atoms and so were absorbed by the gas;
as the temperature dropped (after sufficient time) the photons no longer had the energy to do this and so could go through; ***[3]***