N11/4/PHYSI/HP3/ENG/TZ0/XX/M

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MARKSCHEME

November 2011

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. 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. 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. Indicate this with **ECF** (error carried forward).

10. 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. Indicate this by writing **–1(U)** at the first point it occurs and **U** on the cover sheet.

11. 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.

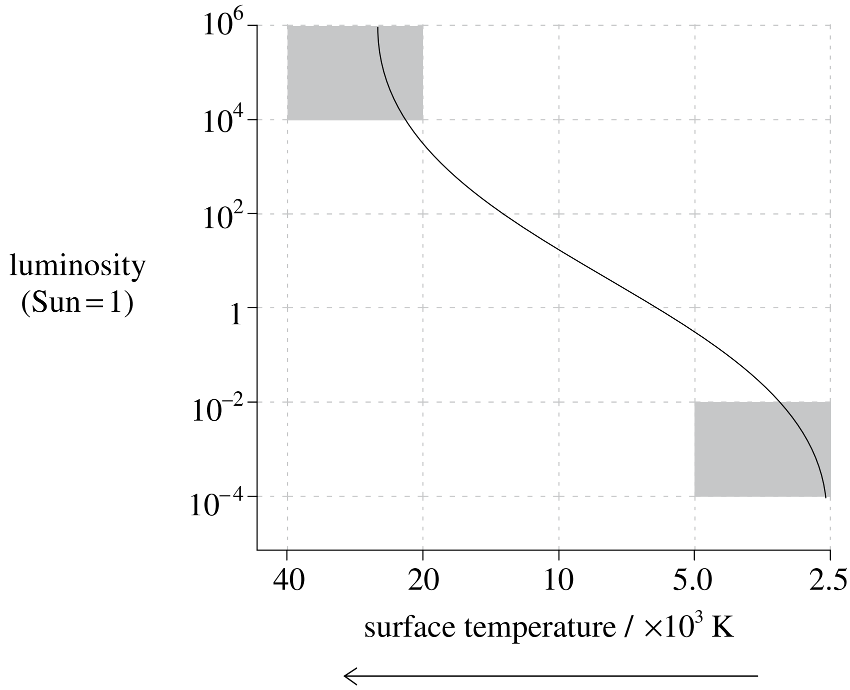
    e.g. if the answer is 1.63:

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

    Indicate the mark deduction by writing **–1(SD)** at the first point it occurs and **SD** on the cover sheet.

Option E — Astrophysics

E1. (a)

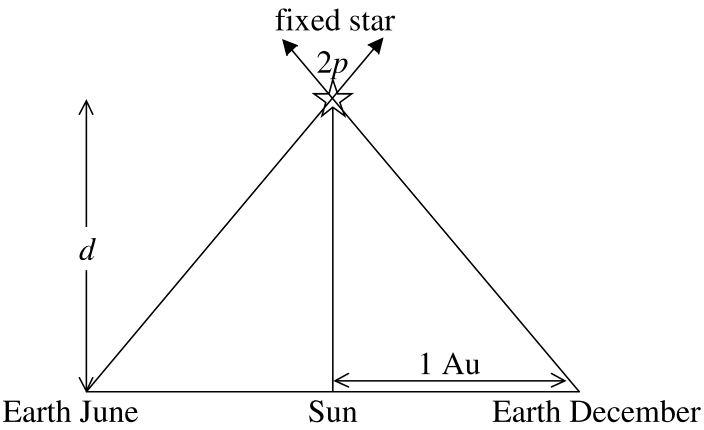


any suitable line from anywhere in top left-hand quadrant; *(accept a straight line)*
to bottom right-hand quadrant; ***[2]***
The shaded areas are the limits within which the line must be drawn.

(b) (i) distance at which 1 AU subtends an angle of 1 arcsec / distance at which the angle subtended by the radius of Earth's orbit is 1 arcsec; ***[1]***

(ii) $p = \left(\frac{1}{d} =\right) 0.56$ arcsec; ***[1]***

(c)



Labelled diagram should relate to the following points:
measure against the fixed stars the angle Barnard's star subtends at Earth in June and again in December;
difference between the two angles is twice the parallax angle;
orbital radius of Earth about Sun is 1 AU so distance to star is computed from $d = \frac{1}{p}$; ***[3]***

(d) (i) $L = 4\pi b d^2$;

$= 4 \times 3.14 \times 3.6 \times 10^{-12} \times [1.8 \times 3.1]^2 \times 10^{32}$;

$= 1.4 \times 10^{23}$ W ;

$\approx 10^{23}$ W **[3]**

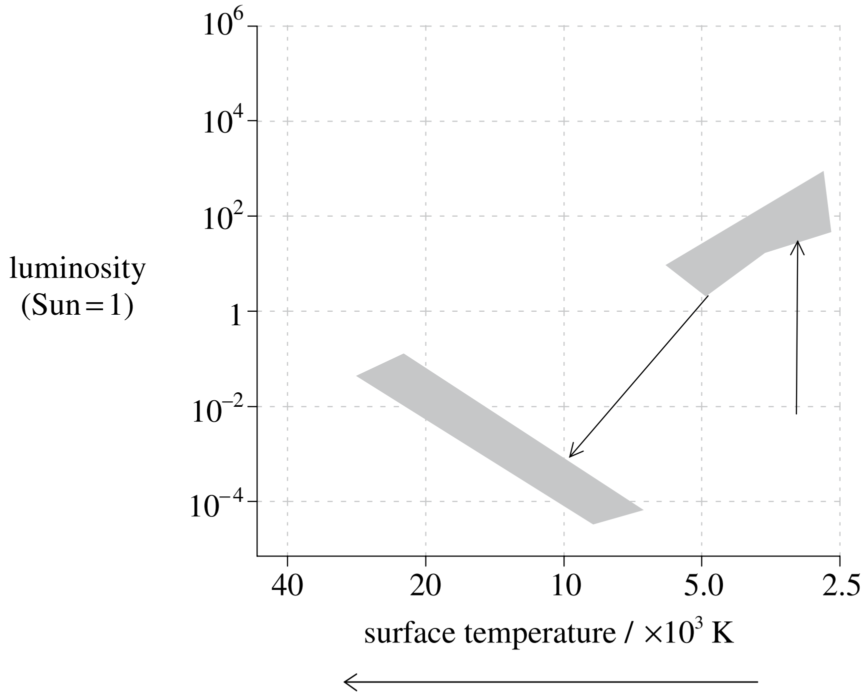
(ii) $A = \dfrac{L}{\sigma T^4}$;

$= \dfrac{1.4 \times 10^{23}}{5.67 \times 10^{-8} \times 3.8^4 \times 10^{12}}$; *(allow ECF from (d)(i))*

$= 1.184 \times 10^{16}$ m^2 ;

$\approx 10^{16}$ m^2 **[3]**

(e)



approximate starting position [$10^{-1} \rightarrow 10^{-3}$, $3000 \rightarrow 4000$];
line to region of red giants;
line from red giants to white dwarfs; **[3]**
The shaded areas are the limits within which the lines must be drawn.

E2. (a) because of the Doppler effect;
light from sources moving away from an observer is observed to have a lower frequency than from the sources when stationary / redshift indicates motion away from observer/Earth; ***[2]***

(b) (i) this is the value of density for which the universe will begin to contract after an infinite amount of time; ***[1]***
Do not accept "density at which universe is flat".

(ii) if the density of the universe is less than the critical density it will continue expanding forever;
if the density is greater than the critical density then it will after a certain amount of time begin to contract;

the behaviour of galaxies suggests that there is more matter in the universe than is actually observed; *(allow other relevant comment about dark matter)*

without knowing the mass of this matter the density cannot be determined; ***[4]***

E3. (a) the recessional speed of galaxies from Earth is proportional to their distance from Earth; ***[1]***

or

$v = Hd$; *(with symbols defined)*

(b) (i) $v = c\dfrac{\Delta\lambda}{\lambda}$;

$= 3.0\times10^5 \times \dfrac{134}{656}$;

$= 6.13\times10^4 \text{ km s}^{-1}$ ***[2]***

(ii) $H = \dfrac{v}{d}$;

$= \left(\dfrac{6.13\times10^4}{940} =\right) 65.1 \text{km s}^{-1} \text{ Mpc}^{-1}$; ***[2]***

(iii) $T = \dfrac{1}{H}$;

$= \dfrac{3.1\times10^{19}}{65.1} = 4.76\times10^{17} \text{ s}$;

$\approx 10^{17} \text{ s}$ ***[2]***

Option F — Communications

F1. (a) *signal wave*:
the wave that carries information about the source / the information wave;

carrier wave:
the wave that transmits information from transmitter to receiver / the wave that is modulated by the signal wave; ***[2]***

(b) (i) the frequency of the carrier wave is kept constant;
and the audio frequency signal wave is used to vary the amplitude of the carrier wave; ***[2]***

(ii) the amplitude of the carrier wave is kept constant;
the carrier wave frequency is varied;
in direct proportion to changes in the amplitude of the audio frequency signal wave; ***[3]***

(c) (i) the sideband frequencies are $[f_c + f_s]$ and $[f_c - f_s]$;
bandwidth $\left(=[f_c + f_s]-[f_c - f_s]\right)=10$;
$2f_s = 10$ so $f_s = 5.0\,\text{kHz}$; ***[3]***

(ii) time between two maxima $= \dfrac{1}{5.0\times10^3} = 2.0\times10^{-4}$ (s);

frequency of carrier wave $= \dfrac{1.8\times10^4}{2.0\times10^{-4}}$;
$= 9.0\times10^7 = 90\,\text{MHz}$ ***[2]***

F2. (a) much less subject to noise / noise can be removed more easily;
transmission rate is not dependant on rate at which information is encoded;
different types of information can be transmitted using the same channel;
data can be compressed;
any other sensible advantage; ***[2 max]***

(b) (i) provides reference pulses/synchronization against which the 0s and 1s of the binary data can be distinguished / *OWTTE*; ***[1]***

(ii) converts the data/information to a string of binary digits; ***[1]***

(c) 0.25 MHz; ***[1]***

(d) ratio of $n = \frac{1.41}{1.44}(= 0.979)$;

path difference between B and A $= 2.00 \times 10^4 - \frac{2.00 \times 10^4}{0.979} = 4.00 \times 10^2$ (m);

time difference $= \frac{4.00 \times 10^2}{2.10 \times 10^8}$;

$\approx 2.00 \times 10^{-6}$ s ***[3]***

F3. (a) (i) the amplifier has a very high open loop gain $\left(\text{defined from } A = \frac{V_{\text{OUT}}}{V_+ - V_-}\right)$;

this means that $V_+ \approx V_-$;
since in the circuit $V_+ = 0$ then $V_- = 0$;
because of the very high input resistance no current will flow into the amplifier at V_- input so P remains at 0 V / *OWTTE*; ***[4]***

(ii) let I be the current at input then $V_{\text{IN}} = IR_1$ and $V_{\text{OUT}} = -IR_2$;
therefore $G = \frac{V_{\text{OUT}}}{V_{\text{IN}}} = -\frac{IR_2}{IR_1} = (-)\frac{R_2}{R_1}$; ***[2]***

(b) *look for these main points*:
(when the thermistor is cold) the variable resistor is used to set the potential at the inverting input (to some fixed value less than the potential at P);
the output of the amplifier is saturated at –15 V and so the LED is unlit;
as the thermistor warms up its resistance decreases;
the potential at P will increase until at a particular temperature, the potential at P is just greater than the potential at the inverting input;
the output now goes high (saturates) to +15 V and the LED will light; ***[4 max]***

Option G — Electromagnetic waves

G1. (a) a varying magnetic and electric field at right angles to each other;
vibration of E and B fields at right angles to the direction of propagation of the wave;
transverse wave;
same speed in a vacuum; ***[2 max]***

(b) the energy required to excite ozone molecules/electrons in ozone molecules;
is equal to the energy of photons in UV light; ***[2]***

or

the resonance frequency of ozone molecules;
matches frequency of UV radiation;

G2. (a) (angular magnification = linear magnification so) $M = \frac{D}{u}$;

$\frac{1}{u} + \frac{1}{D} = \frac{1}{f}$;

so $\frac{D}{u} = \frac{D}{f} + 1 = M$; ***[3]***

(b) (i) ray through centre of objective lens and ray through f_o;
to show formation of intermediate image; ***[2]***

(ii) $\frac{1}{v} = \frac{1}{1} - \frac{1}{1.5}$;
$v = 3.0\,\text{cm}$; ***[2]***
*Award **[2]** for a bald correct answer.*

(c) (i) rays parallel to principal axis at edge of lens;
brought to different foci from those near to the centre of the lens; ***[2]***

(ii) different colours have different refractive indices/speeds;
different colour refracted at different amounts / image formed for each colour; ***[2]***

G3. (a) greater amplitude/intensity from both slits;
bright fringes are brighter;
dark fringes are unchanged; ***[3]***

(b) brighter / more intense
sharper / more well-defined ***[2]***

G4. (a) fringes arise as a result of interference between light reflected from top and bottom plates;
there is a phase difference of π at bottom reflection;
hence constructive interference when $2d = \left(n + \frac{1}{2}\right)\lambda$ and destructive when $2d = n\lambda$; ***[3]***

(b) the fringe separation would decrease;
the distance between the points/places/positions where the light is in phase or antiphase would be shorter; ***[2]***

G5. (a) *Look for these main points*:
electrons give energy to electrons in the innermost orbit/lowest energy levels;
these electrons ejected from the atom;
energy levels filled by electrons from higher energy levels;
emitting photons with wavelength equal to characteristic spectra wavelength; ***[3 max]***

(b) $\lambda = \frac{hc}{eV}$

$\lambda = 6.63\times10^{-34}\times3\times10^{8} / 1.6\times10^{-19}\times50\times10^{3}$;

$= 2.5\times10^{-11}$ m ; ***[2]***

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

Option H — Relativity

H1. (a) (i) (a reference frame) in which Newton's first law holds true/that is not accelerating/that is moving with constant velocity; ***[1]***

(ii) the speed of light in a vacuum/free space is the same for all inertial observers; ***[1]***

(b) *Look for these main points*:
signal from switch travels at same speed *c* to each lamp;
but during signal transfer C_1 moves closer to/C_2 moves away from source of signal;
since speed of light is independent of speed of source, signal reaches C_1 before C_2 /C_2 after C_1;
according to Vladamir C_1 registers arrival of signal before C_2/C_2 registers arrival of signal after C_1; ***[4]***

(c) (i) $\gamma = \frac{1}{\sqrt{1-(0.70)^2}} = 1.4$;
$L_0 = \gamma L$;
$= 1.4\,\text{m}$; ***[3]***

(ii) Natasha
since proper length is defined as the length of the object measured by the observer at rest with respect to the object; ***[1]***

(d) (i) *Look for an argument along these lines*:
on the return of the travelling twin according to the twin on Earth the travelling twin will have aged very little compared to himself/herself;
however, since time dilation is symmetric it could be the twin on Earth who has done the least aging;
experiment suggests that it is the travelling twin who ages the least; ***[3]***

(ii) because of the accelerations undergone by the travelling twin the situation is not symmetric / travelling twin is not in the same inertial frame of reference/ changes inertial frame of reference; ***[1]***

(e) (i) $(0.96 \times 3.0 \times 10^8 \times 3.1 \times 10^{-6}) = 890\,\text{m}$; ***[1]***

(ii) $\gamma = \frac{1}{\sqrt{1-(0.96)^2}}$;
distance $= (3.57 \times 890 =)$ ***or*** $(3.57 \times 0.96 \times 3.0 \times 10^8 \times 3.1 \times 10^{-6} =)\ 3200\,\text{m}$; ***[2]***

(f) using the laboratory half-life, most of the muons would have decayed before reaching Earth;
however many muons are detected at the surface;
showing that the half-life is dilated / to the muons the distance travelled is contracted; ***[3]***

H2. (a) $V = (\gamma - 1)938 \times 10^6$;

$\gamma = \left(\dfrac{1}{\sqrt{1-(0.970)^2}} = \right) 4.11$;

$V = (3.11 \times 938 \times 10^6 =) 2.92 \times 10^9\ \text{V}$ ***or*** $2.92\ \text{GV}$; ***[3]***

(b) (i) $3.86 \times 10^3\ \text{MeV c}^{-2}$ ***or*** $3.86\ \text{GeV c}^{-2}$; ***[1]***

(ii) $3.74 \times 10^3\ \text{MeV c}^{-1}$ ***or*** $3.74\ \text{GeV c}^{-1}$; ***[1]***

H3. (a) *Look for an argument along these lines*:
the speed of light is independent of speed of source;
because of the direction of acceleration;
to Kim it will appear as if L_1 is moving away from her;
light from L_1 will therefore be Doppler shifted toward the red end of the spectrum; ***[3 max]***

or

accelerating spaceship is equivalent to being at rest in a gravitational field / *OWTTE*;
photons leaving the source therefore gain potential energy and lose kinetic energy;
since $E = hf$;
Kim will measure a lower frequency;

(b) according to the equivalence principle the accelerating spaceship is equivalent to a frame of reference at rest in a (uniform) gravitational field / can be regarded as being at rest on the surface of a planet/large mass / *OWTTE*;
if light is red shifted from L_1 then this implies period of the light source is longer therefore time is slower / *OWTTE*; ***[2]***

Option I — Medical physics

I1. (a) (i) the power (incident) per unit area (of the eardrum); *[1]*

(ii) $IL = \lg\left[\frac{I}{I_0}\right]$
with symbols defined; *[1]*

(b) the ear responds to differences in intensity rather than total intensity;
each time the intensity is doubled the loudness will be heard to increase by the same amount;
the response of the ear to intensity is therefore logarithmic; *[3]*

or

Accept a mathematical argument.
introductory statement *e.g.* each time the intensity is doubled the loudness will be heard to increase by the same amount;
therefore $dL \propto \frac{dl}{I}$;
hence $L = k\lg\left[\frac{I}{I_0}\right]$ where k is a constant and $L = 0$ when $I = I_0$;

(c) $\text{difference} = 10\left[\lg\left[\frac{I_{\text{door}}}{I_0}\right] - \lg\left[\frac{I_{\text{chat}}}{I_0}\right]\right]$;

$= 10\lg\left[\frac{I_{\text{door}}}{I_{\text{chat}}}\right]$;

$= \left(10\lg\left[\frac{10^{-4}}{10^{-6}}\right] = \right) 20\,\text{dB}$; *[3]*

I2. (a) an electric field applied along the axis of a piezoelectric crystal causes the crystal to expand or contract;
a high frequency alternating *E* field will cause the crystal to oscillate at the frequency of the applied field;
the oscillations are transferred to the surrounding air producing ultrasound; ***[3]***

(b) no contrast between heart and surroundings as X-rays will not be absorbed by the heart;
ultrasound will be reflected/transmitted by different amounts by the slightly differing densities and depths of the heart tissue; ***[2]***
Do not accept answers based on "X-rays are harmful".

(c) acoustic impedance $=$ speed of sound $\times$ density;
acoustic impedance of skin $= 5\times700 = 3500\times$ acoustic impedance of air; ***[2]***

(d) acoustic impedance of skin is very much greater than that of air so nearly all incident ultrasound is reflected at air/skin boundary;
gel has same acoustic impedance as skin so nearly all ultrasound will be transmitted through the skin; ***[2]***

(e) high frequency ultrasound gives better resolution;
but is subject to more attenuation;
the further the distance the ultrasound travels the more it is attenuated;
the deeper an organ therefore the lower the frequency used in order to minimize attenuation / a compromise has to be made between resolution and attenuation; ***[4]***

I3. (a) the energy absorbed per unit mass; ***[1]***

(b) the higher quality factor of α means that the same absorbed dose of α as γ;
has a much more damaging effect than that of γ;
on the same volume of tissue;
some comment as to choice *i.e.* less active alpha source is needed; ***[3 max]***
*Award **[1]** if only definition of dose equivalent H = QD with terms defined is given.*

(c) energy required to produce ion pairs $= (1.7\times10^{10}\times34\times1.6\times10^{-19} =)\ 9.248\times10^{-8}\,(\text{J})$;
mass of air $= (1.2\times7.8\times10^{-4} =)\ 9.36\times10^{-4}\,(\text{kg})$;
absorbed dose $= \left(\frac{E}{m} =\right)\frac{9.248\times10^{-8}}{9.36\times10^{-4}} = 0.988\times10^{-4}\,(\text{J kg}^{-1})$;
dose equivalence $=$ Q $\times$ absorbed dose $= 20\times0.998\times10^{-4} = 2.0\,\text{mSv}$;
therefore can be used; ***[5]***

Option J — Particle physics

J1. (a) (i) particle that has no internal structure/is not made out of any smaller constituents; ***[1]***

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

(b) $\Delta t = \frac{h}{4\Delta\pi E}$;

$= \frac{6.6\times10^{-34}}{4\times3.14\times1.5\times1.6\times10^{-19}}$;

$= 2.2\times10^{-16}$ s ***[2]***

(c) (i) intermediate vector boson/W boson; ***[1]***

(ii) $m = \frac{h}{4\pi Rc}$;

$= \left(\frac{6.6\times10^{-34}}{4\times3.14\times10^{-18}\times3.0\times10^{8}} = \right)1.75\times10^{-25}$ kg;

$= \frac{1.75\times10^{-25}\,c^2}{e} = 109\,\text{GeV c}^{-2} \approx 10^2\,\text{GeV c}^{-2}$; ***[3]***

(iii) the neutron quark structure is udd and the proton uud;
a d quark in the neutron changes to a u quark by emitting a W boson; ***[2]***

J2. (a) the frequency of rotation (of the particles) does not depend on the path that they follow;
the frequency of the alternating potential applied across the gap is made to be the same as the frequency of rotation;
each time the particles cross the gap they will be accelerated;
provided that the direction of the electric field is in the correct direction / *OWTTE*; ***[4]***

(b) angular speed $= 2\pi f$;

linear speed $= 2\pi fr = 2\pi\times10^{8}\times0.34 = 2.135\times10^{8}\,\text{m s}^{-1}$;

KE (eV) $= \frac{1}{2}\frac{mv^2}{e} = \frac{1.673\times10^{-27}\times[2.135]^2\times10^{14}}{2.0\times1.6\times10^{-19}} = 238\,\text{MeV}$;

$E = (m_0c^2 + K) = 938 + 238$;

$\approx 1200\,\text{MeV}$ ***[4]***

(c) instead of using a single magnet many smaller magnets are used; ***[1]***

J3. (a) the (presently accepted) theory that describes the electromagnetic and weak interactions of quarks and leptons / the electromagnetic, weak interactions of quarks and electrons and the strong interaction of baryons; ***[1]***

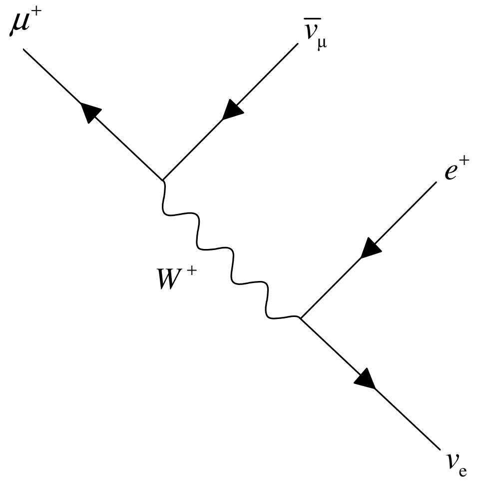
(b) (i)

	μ^+	e^+	ν_e	$\overline{\nu}_\mu$
L	–1	–1	+1	–1;
L_e	0	–1	+1	0;
L_μ	–1	0	0	–1;

[3]

*Award **[1]** for each correct row.*

(ii)



W^+;
any other two correct;
and other two correct; ***[3]***

(c) (i) the scattering of high energy leptons from the particles in the interior of the proton / *OWTTE*; ***[1]***

(ii) it is possible to measure the total momentum carried by the quarks inside the nucleon;
this total momentum does not equal the momentum of the nucleons;
so neutral objects must be present in the nucleon carrying some of its momentum; ***[3]***