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MARKSCHEME

May 2013

PHYSICS

Higher Level

Paper 3

18 pages

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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.

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

E1. (a)   apparent magnitude / (log scale of) brightness of star viewed from 10 pc /
            logarithmic scale of luminosity of a star;   *[1]*

   (b)   (i)   star X
                because it has a greater apparent brightness;   *[1]*
                To award [1] an explanation is needed.

         (ii)   star X
                looks brighter from Earth even though it has lower luminosity/greater
                absolute magnitude than star Y;   *[1]*
                To award [1] an explanation is needed.

   (c)   (i) $d = \sqrt{\dfrac{L}{4\pi b}}$;

                $d = \left(\sqrt{\dfrac{4.9 \times 10^{30}}{4\pi \times 2.5 \times 10^{-8}}} = \right) 3.9 \times 10^{18} \text{ m}$;   *[2]*

                Award [2] for a bald correct answer.

         (ii)   (star X is class M so its) temperature is about $3000\,(\pm 1000)\,\text{K}$;

                $R = \sqrt{\dfrac{L}{4\pi\sigma T^4}} \quad \left(= \sqrt{\dfrac{4.9 \times 10^{30}}{4 \times \pi \times 5.68 \times 10^{-8} \times 3000^4}} \right)$;

                $R = 2.9 \times 10^{11} \text{ m}$;   *[3]*

                *Accept a temperature range of 2000 K to 4000 K so that the radius range is
                1.6×10^{11} to 6.6×10^{11}.*
                Award [3] for a bald correct answer.

         (iii)   high luminosity / high radius / low temperature;
                 a red giant/red supergiant;   *[2]*

   (d)   star's absorption spectrum has dark lines indicating absorption of light of specific
         energy/frequency/wavelength;
         the dark lines correspond to the emission line spectra of different elements /
         different elements have specific wavelengths absorbed;   *[2]*

E2. (a) black-body radiation (at a temperature of about 3 K);
<u>electromagnetic radiation</u> in the microwave region;
isotropic/uniform in all directions;
electromagnetic radiation that has no specific point of origin / *OWTTE*;   *[2 max]*

(b) (i)
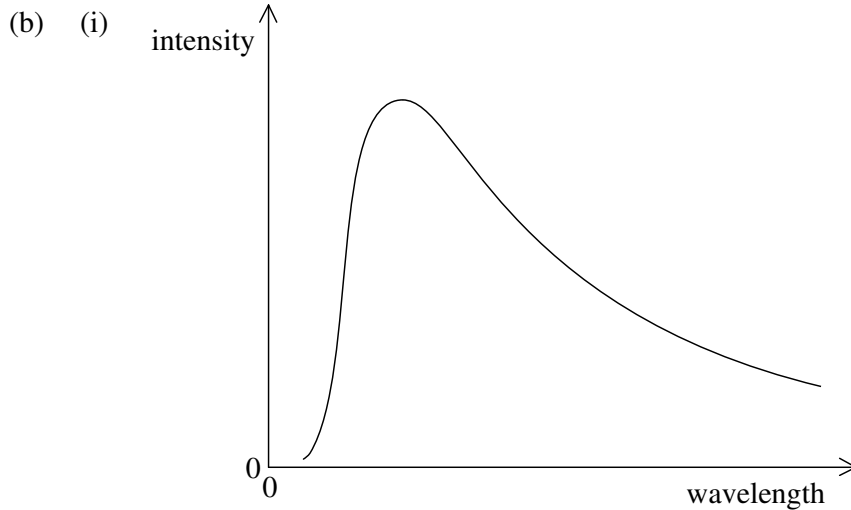
standard black-body curve:
shows maximum/peak;
curve not symmetric about peak, left-hand side much steeper than
right-hand side;   *[2]*

(ii) the wavelength λ_0 at maximum intensity is measured;

the temperature is obtained from Wien's law / $T = \dfrac{2.9 \times 10^{-3}}{\lambda_0}$;   *[2]*

(iii) CMB, filling all space, was predicted by the Big Bang model;
the temperature/wavelength of the radiation is consistent with (cooling due to)
expansion/red-shift;   *[2]*

E3. (a) $\dfrac{L_A}{L_S} = 100 = \left[\dfrac{M_A}{M_S} \right]^{3.5}$;

$\left(\dfrac{M_A}{M_S} = 100^{1/3.5} = 3.7 \right) \approx 4$;   *[2]*

Award marks only if a ratio is calculated.

(b) (i) depletion of hydrogen in the core / fusion moves to outer layers;   *[1]*

(ii) $1.4 M_\odot < M < 3 M_\odot$;   *[1]*

Allow between $2 M_\odot$ and $3 M_\odot$ as the upper bound OV limit.

E4. (a) recessional speed of (distant) <u>galaxies</u> is proportional to their separation / $v = Hd$; **[1]**
Symbols must be defined for the equation.

(b) (i) $\left(\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c} \Rightarrow \right) v = 3 \times 10^5 \, \mathrm{m\,s^{-1}}$ ***or*** $3 \times 10^2 \, \mathrm{km\,s^{-1}}$;

<u>towards</u> Earth; **[2]**

(ii) $390 \, \mathrm{km\,s^{-1}\,Mpc^{-1}}$; *(allow other units: $390000 \, m\,s^{-1}\,Mpc^{-1}$, $1.3 \times 10^{-17}\,s^{-1}$)* **[1]**

(iii) the value is wrong/cannot be used/cannot be relied upon / we cannot use this galaxy to calculate H;
Hubble's law only applies to galaxies moving away / more distant galaxies; **[2]**

Option F — Communications

F1. (a) (i) period is $10\,\mu s$;

$$f_C = \frac{1}{10\,\mu s} = 100\,kHz \; ;$$ *[2]*

Award [2] for a bald correct answer.

(ii) period is time from peak to peak *ie* $100\,\mu s$;

$$f_s = \frac{1}{100\,\mu s} = 10\,kHz \; ;$$ *[2]*

Award [2] for a bald correct answer.

(iii) $20\,kHz$; *[1]*

(iv) valid working, *eg* $\dfrac{15-5}{2}$;

$5.0\,mV$; *[2]*

(b)
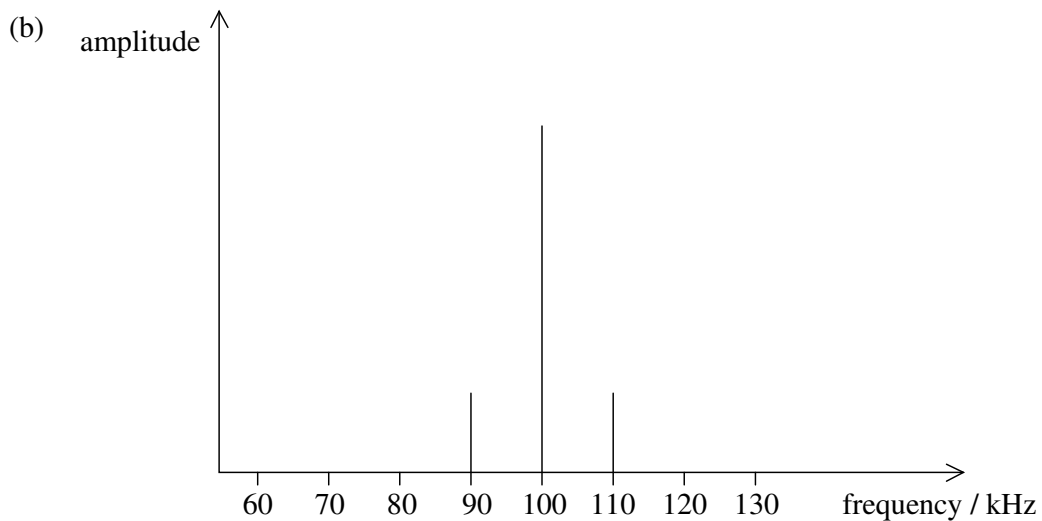
central maximum at $100\,kHz$;
shorter maxima at $90\,kHz$ and $110\,kHZ$; *[2]*

F2. (a) $22\,kHz$;
the reconstructed signal will not be a faithful reproduction of the original if the
sampling frequency is not at least twice the highest frequency in the signal; *[2]*

(b) (i) $(44\times10^3\times32=)1.4\times10^6\,bits\,s^{-1}$; *[1]*

(ii) $\left(\dfrac{1}{1.4\times10^6}=\right)0.71\,\mu s$; *[1]*

F3. (a) (i)   the loss of power/energy during the transmission of a signal;   **[1]**

      (ii)   resistive heating / EM radiation losses;   **[1]**

  (b) (i)   total allowed loss of power is $-10\lg\dfrac{12}{240}=13\,\text{dB}$;

          $\text{loss}=120\times15-N\times52$;
          $1800-N\times52=13$;
          gives $N=34.4$ so $N=35$ required;   **[4]**

      (ii)   fewer amplifiers needed;
          better quality of transmission;
          greater bandwidth;
          greater security;
          no thermal/ohmic losses;   *[1 max]*

F4. (a) (i)   the output voltage has opposite sign to that of the input / negative feedback
          fed into inverting input;   **[1]**

      (ii)   point between resistors next to inverting input;   **[1]**

      (iii)   realization that I is same through each R / op-amp current is zero;
          pd across $R_1=V_{\text{IN}}$ and pd across $R_2=V_{\text{OUT}}$;

$$G=\frac{V_{\text{OUT}}}{V_{\text{IN}}}=\frac{-IR_2}{IR_1}=\text{required result};$$
                                 [3]

  (b) (i) $-3.0\,\text{V}$;   **[1]**

      (ii) $-12\,\text{V}$;   **[1]**

F5.   base stations and phone exchange signals;
     base stations relay call to cellular exchange;
     cellular exchange monitors signal strength from base stations;
     cellular exchange selects the base station with the strongest signal;
     cellular exchange allocates frequency for call;   *[3 max]*

Option G — Electromagnetic waves

G1. (a) (i) no change (of $90°$); *[1]*

(ii) correct distance shown, *eg* from peak to peak/between any successive points in phase; *[1]*

(b) all travel with the same speed in <u>vacuum</u> / in free space;
can propagate in vacuum;
are transverse;
can be polarized;
can carry energy/momentum; *[1 max]*
Allow other valid properties.

G2. (a)
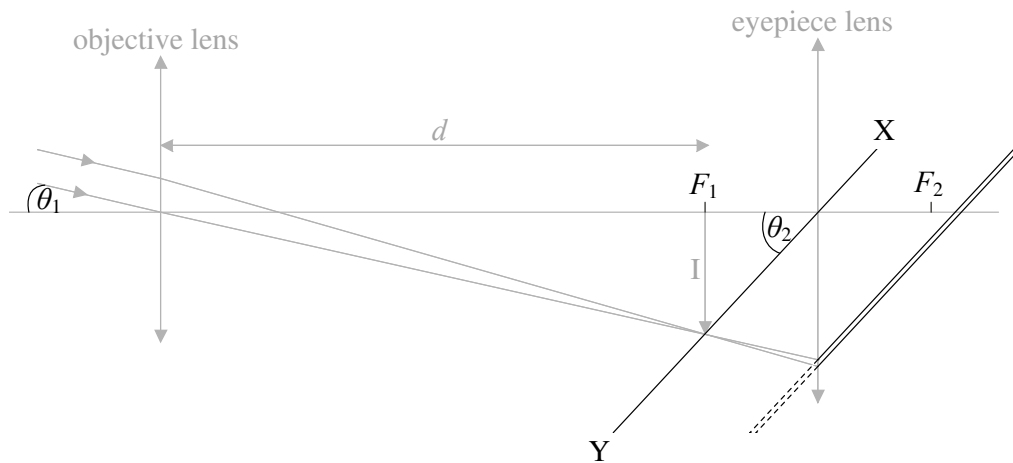
(i) $\frac{1}{d}=\frac{1}{f_0}-\frac{1}{u}$ where u is the object distance from the lens;

since u is very large $\frac{1}{u}$ is negligible/zero;

(and so $d=f_0$) *[2]*
Accept equivalent answers.

(ii) at position of image in objective and an equal distance on the other side of the lens; *(judge by eye)* *[1]*

(iii) *see diagram above*:
first ray, after refraction, as shown;
second ray, after refraction, parallel to first ray;
extrapolation to infinity; *(allow even if refraction angles are wrong)* *[3]*
Accept alternative correct rays to those shown.

(iv) both angles as shown or their equivalent; *[1]*

(b) $M=\frac{26}{4.0}=6.5$;
$6.5\times2.2=14°$; *[2]*

G3. (a) (i) the path difference between the two rays at M is zero;
so constructive interference occurs; *[2]*

(ii) distance MP is $\dfrac{D}{2d}$;

and so $\lambda = \left(\dfrac{2.62 \times 10^{-3} \times 2 \times 0.150 \times 10^{-3}}{1.20} = \right) 6.55 \times 10^{-7}$ m; *[2]*

Award [2] for a bald correct answer.

(b)
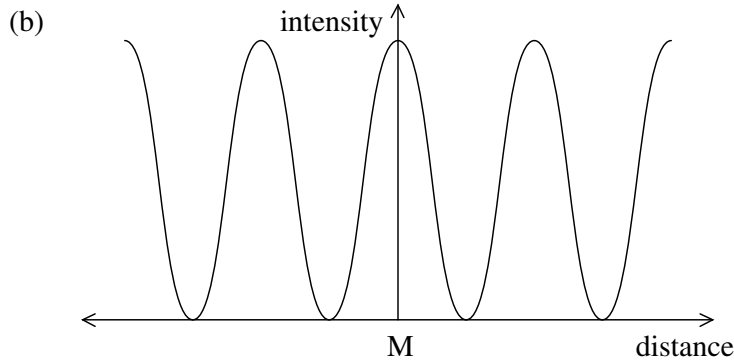
maxima of equal intensity;
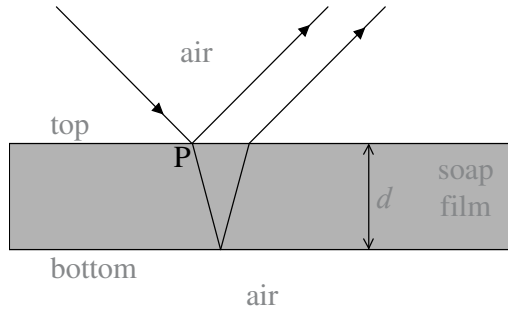equally separated; *(judge by eye)* *[2]*

(c) position of maxima the same;
maxima narrower/sharper;
maxima brighter;
appearance of secondary maxima; *[2 max]*

G4. (a) (i) $\lambda_{\min} = \dfrac{hc}{eV} = \dfrac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 28 \times 10^3}$;

$\lambda = 4.439 \times 10^{-11}$ m; *[2]*

(ii) (the minimum wavelength is obtained when) electrons give all their energy
to a single photon; *[1]*

(b) $\left(2d \sin\theta = \lambda \Rightarrow d = \dfrac{\lambda}{2\sin\theta} = \right) \dfrac{4.4 \times 10^{-11}}{2\sin 11^\circ}$;

$d = 1.2 \times 10^{-10}$ m; *[2]*

Award [2] for a bald correct answer.

G5. (a)

P as shown;   *[1]*

(b) (i)   for destructive interference, use of $2\mu d = n\lambda$ to give $\lambda = 2\mu d$ (*ie* $n=1$);
$\lambda = 2 \times 1.34 \times 225$;
(603nm)   *[2]*

(ii) the reflected light is white minus the wavelengths that suffer destructive
interference;
some colours are determined by the missing wavelengths;
some colours are enhanced due to constructive interference;   *[2 max]*

Option H — Relativity

H1. (a) the length of an object in its rest frame / the length of an object measured when at rest relative to the observer; *[1]*

   (b) (i) 1.67; *[1]*

   (ii) 72 m; *[1]*

   (iii) 43 m; *[1]*

   (c) Albert must agree that Mileva receives light from the two lamps simultaneously;
   but for Albert the light from the exit lamp travels further than the light from the entrance lamp;
   because Mileva is moving to the left/towards the light from the entrance lamp;
   the speed of light is constant *ie* same in both directions/for both observers/from both sources;
   (so for Albert the exit lamp must switch on first) *[3 max]*

   (d) (i) 3.0×10^{-7} s ; *[1]*

   (ii) Mileva measures proper time;
   $$\left(\gamma \times \frac{72}{0.80 \times 3.0 \times 10^8} \right) = 5.0 \times 10^{-7} \text{ s} ;$$ *[2]*

   or

   according to Albert a length of 120 m must move past him;
   and this takes $\left(\dfrac{120}{0.80 \times 3.0 \times 10^8} \right) = 5.0 \times 10^{-7}$ s ;
   Award [2] for a bald correct answer.

H2. (a) the number of half-lives that go by until muons make it to sea level is $\dfrac{6.0}{1.5} = 4$;

and so the number of muons per hour would be $\dfrac{570}{2^4} = \dfrac{570}{16}\,(= 35.6)$;

(≈ 36) *[2]*

(b) (i) $\gamma = 3.985$;

so the dilated half-life is $3.985 \times 1.5 = 5.977 \approx 6.0\,\mu s$; *[2]*

(ii) 285 muons per hour represents a half-life of $6.0\,\mu s$;

this time is four times greater than in the muon frame, and so confirms time dilation; *[2]*

H3. (a) $E = \sqrt{p^2 c^2 + (mc^2)^2} = \sqrt{1600^2 + 938^2} \approx 1855\,\text{MeV}$;

$\Delta E = 1855 - 938 = 917\,\text{MeV}$;

potential difference, $V \approx 920\,\text{MV}$; *(this marking point must be explicit)* *[3]*

Award [3] for a bald correct answer.

(b) $= \dfrac{1855}{938} = 1.977$ *or* $\gamma - 1 = \dfrac{917}{938}$;

$\dfrac{v}{c} = \sqrt{1 - \dfrac{1}{\gamma^2}} = 0.86\text{c}$ *or* $v = \dfrac{1600}{938 \cdot 1.997}\text{c} = 0.86\text{c}$; *[2]*

Award [2] for a bald correct answer.

H4. (a) a frame of reference accelerating in (outer space) is equivalent to a frame of reference at rest in a gravitational field / gravitational effects are indistinguishable from inertial effects;   *[1]*

(b) balloon moves to the right;
rocket frame is equivalent to a rocket at rest in a gravitational field directed to the left;
helium balloons rise in gravitational fields;   *[3]*

(c) (i) so that the star could be seen during the day;   *[1]*

(ii)
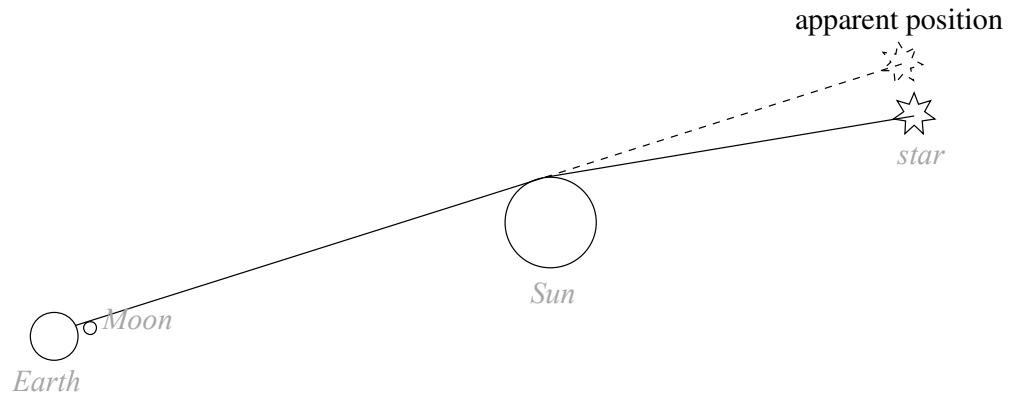
ray from star curving past the Sun towards the Earth and that ray extended backwards along a straight line to a position higher/lower than real position of star;   *[1]*
Allow ray path to travel above or below the Sun.

(iii) the position of the star when light from the star reaches the Earth without going past the Sun;   *[1]*

(iv) the angle of deflection will be greater;
a greater mass will cause a greater curvature of spacetime;   *[2]*

Option I — Medical physics

I1. (a) $10\lg \dfrac{I}{1.0\times10^{-12}}$ dB where I is the intensity of sound; *[1]*

(b) (i) $10\lg \dfrac{I}{1.0\cdot10^{12}}=105$ to give $I=0.0316\,\mathrm{W\,m^{-2}}$;

$P=IA=0.0316\times58\times10^{-6}$;
$(=1.8\,\mu\mathrm{W})$ *[2]*

(ii) $10\lg \dfrac{I}{1.0\times10^{-12}}=90 \Rightarrow I=0.0010\,\mathrm{W\,m^{-2}}$;

intensity decreases by $\dfrac{0.0010}{0.0316}=0.0316=\dfrac{12^2}{x^2}$;

and so distance must become $\dfrac{12}{\sqrt{0.0316}}=67\,\mathrm{m}$ *or* $68\,\mathrm{m}$; *[3]*

Award [3] for a bald correct answer.

I2. (a) the probability per unit length that a particular X-ray photon will be absorbed; *[1]*

or

$I=I_0e^{-\mu x}$; *(with symbols defined)*

(b) (i) the attenuation coefficient is large which means that these low energy photons will be mostly absorbed (by muscles);
and so will not contribute to the imaging process; *[2]*

(ii) the patient avoids unnecessary harmful radiation; *[1]*

(iii) the linear attenuation coefficient is $\mu=3.0\,\mathrm{cm^{-1}}=0.30\,\mathrm{mm^{-1}}$ (from graph);

and so fraction of intensity transmitted is $e^{-0.30\cdot3.0}=0.41$; *[2]*

I3. (a) a magnetic field is applied (*eg* to a patient);
protons/H nuclei (in patient) have spin/magnetic moment;
which align with the field / have different energy levels;
a radio frequency (RF) field (at resonant/Larmor frequency) is turned on;
which changes the spin orientation/energy levels;
the protons/nuclei then emit an RF pulse (as they de-excite);
which is detected to determine the position of the proton/nuclei; *[5 max]*

(b) no exposure to harmful radiation;
better quality image; *[2]*

I4. (a) gamma rays will not all be absorbed by and will leave the body;
so that they can be detected and monitored; *[2]*

(b) the tumour receives about the same radiation in both cases and so will be damaged;
but in method 1 the radiation travels through different paths, reducing damage to healthy cells; *[2]*

(c) (i) physical half-life is the half-life due to radioactive decay;
biological half-life is the half-life due to physiological/biological processes; *[2]*

(ii) $\dfrac{1}{T} = \dfrac{1}{6.0} + \dfrac{1}{60}$;
$(T = 5.5\,\text{hr})$ *[1]*

(iii) number of decays in 5.5 hr is $(350 \times 10^6 \times 5.5 \times 3600 =)\, 6.9 \times 10^{12}$;
energy deposited is $(140 \times 10^3 \times 6.9 \times 10^{12} \times 1.6 \times 10^{-19} =)\, 0.155\,\text{J}$;
absorbed dose is $\left(\dfrac{0.155}{72} =\right) 2.2\,\text{mGy}$;
dose equivalent is $(1 \times 2.2 =)\, 2.2\,\text{mSv}$; *[4]*
Award [4] for a bald correct answer.

Option J — Particle physics

J1. (a) a baryon consists of three quarks/antiquarks while a meson has one quark and one antiquark; *[1]*

(b) $\dfrac{\hbar}{2} = \dfrac{h}{4\pi} = 5.3 \times 10^{-35}\,\text{J s}$; *[1]*

(c) (i) it is impossible for two identical fermions to occupy the same quantum state; *[1]*

(ii) quarks have a quantum number called colour;
the three otherwise identical quarks in the baryon are distinguished by different colour quantum numbers; *[2]*

(d) (i) positron on lower line with arrow going to the left; *[1]*

(ii) the range is infinite;
because the exchange particle is the massless photon; *[2]*

(e) $e^+ + e^+ \to p^+ + p^+$: baryon number / lepton number;
$e^- + \nu \to e^+ + \bar{\nu}$: electric charge / lepton number; *[2]*

J2. (a) (i) S = 3; *[1]*

(ii) baryon;
to conserve baryon number / has structure sss; *[2]*

(b) $E_A = \sqrt{2 \times 938 \times 3170 + 494^2 + 938^2}$;
$E_A = 2660\,\text{MeV}$;
(since E is the minimum energy) $E_A = 494 + 498 + M_X c^2$;
hence $M_X = 1670\,\text{MeV}\,c^{-2}$; *[4]*
Award [4] for a bald correct answer.

(c) wires (in a grid) are at high potential;
charged particles ionize a gas;
ions collect at wires;
time of arrival can be accurately measured;
the position of the charged particle is determined; *[3 max]*

J3. (a) at high energies/momenta;
quarks behave as free particles/interaction force decreases;   *[2]*

(b) deep inelastic scattering experiments involve electrons colliding with hadrons;
the scattering of the electrons is consistent with "free" quarks/loosely bound
quarks inside the hadrons;   *[2]*

(c)
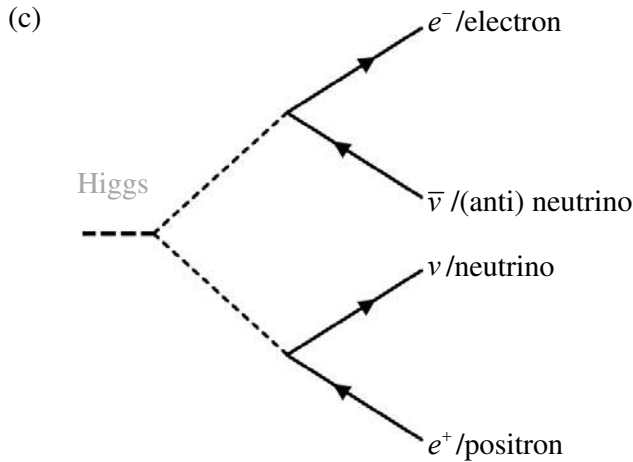
Higgs joining to two W bosons;
W bosons decay to lepton/anti-lepton pairs with at least one pair correctly
labelled;   *[2]*

J4. (a) $\frac{3}{2}kT = 2m_e c^2$;

$\left(T = \frac{4m_e c^2}{3k} = \frac{4 \times 9.1 \times 10^{-31} \times (3 \times 10^8)^2}{3 \times 1.38 \times 10^{-23}} \approx \right) 8 \times 10^9 \text{ K}$;   *[2]*

Award [1] if only one electron is used giving $\approx 4 \times 10^9$ K.

(b) the expression $\frac{3}{2}kT$ only gives the average energy;

since there is a distribution of energies there are photons with this energy even at
lower temperatures;   *[2]*