M12/4/PHYSI/HP3/ENG/TZ2/XX/M

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MARKSCHEME

May 2012

PHYSICS

Higher Level

Paper 3

20 pages

General Marking Instructions

Assistant Examiners (AEs) will be contacted by their team leader (TL) through Scoris™, by e-mail or telephone – if through Scoris™ or by e-mail, please reply to confirm that you have downloaded the markscheme from IBIS. The purpose of this initial contact is to allow AEs to raise any queries they have regarding the markscheme and its interpretation. AEs should contact their team leader through Scoris™ or by e-mail at any time if they have any problems/queries regarding marking. For any queries regarding the use of Scoris™, please contact emarking@ibo.org.

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1. Follow the markscheme provided, award only whole marks and mark only in **RED**.

2. Make sure that the question you are about to mark is highlighted in the mark panel on the right-hand side of the screen.

3. Where a mark is awarded, a tick/check (✓) **must** be placed in the text at the **precise point** where it becomes clear that the candidate deserves the mark. **One tick to be shown for each mark awarded.**

4. Sometimes, careful consideration is required to decide whether or not to award a mark. In these cases use Scoris™ annotations to support your decision. You are encouraged to write comments where it helps clarity, especially for re-marking purposes. Use a text box for these additional comments. It should be remembered that the script may be returned to the candidate.

5. Personal codes/notations are unacceptable.

6. Where an answer to a question or part question is worth no marks but the candidate has attempted the part question, enter a zero in the mark panel on the right-hand side of the screen. Where an answer to a question or part question is worth no marks because the candidate has not attempted the part question, enter an "NR" in the mark panel on the right-hand side of the screen.

7. If a candidate has attempted more than the required number of questions within a paper or section of a paper, mark all the answers. Scoris™ will only award the highest mark or marks in line with the rubric.

8. Ensure that you have viewed **every** page including any additional sheets. Please ensure that you stamp "seen" on any page, in the Options attempted by the candidate, that contains no other annotation.

9. Mark positively. Give candidates credit for what they have achieved and for what they have got correct, rather than penalizing them for what they have got wrong. However, a mark should not be awarded where there is contradiction within an answer. Make a comment to this effect using a text box or the "CON" stamp.

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

E1. (a) (i) a constellation is a collection of stars that form a (recognizable) pattern (as viewed from Earth);
the distances between the stars may be very large;
a stellar cluster is a group of stars held together by (mutual) gravitational attraction/gravity/are physically relatively close;
there can be many thousands of stars in the cluster;
all stars in the cluster were created about the same time; ***[3 max]***

(ii) the (total) power radiated/emitted/produced (by the star); ***[1]***

(iii) luminosity of Aldebaran $= 370 \times 3.9 \times 10^{26} = 1.44 \times 10^{29}$ (W);
$= \sqrt{\dfrac{1.44 \times 10^{29}}{4\pi \times 3.3 \times 10^{-8}}} = 5.9 \times 10^{17}$;
$= \dfrac{5.9 \times 10^{17}}{3.1 \times 10^{16}} = 19$ pc; ***[3]***

(b) (i) a <u>measure</u> of how bright a star appears / a (logarithmic) <u>measure</u> of apparent brightness; ***[1]***

(ii) expressing d in pc;
$M = -0.64$; ***[2]***

(c) (i) *Aldebaran*:
it forms a planetary nebula which then becomes a white dwarf;

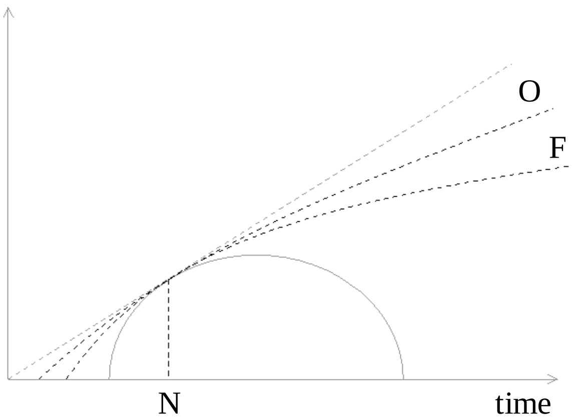
Betelgeuse:
it forms a supernova which then becomes a neutron star/black hole/pulsar; ***[2]***
*To award **[2]** both phases are required in both responses.*
*Award **[1 max]** if intermediate stages (planetary nebula, supernova) are omitted.*

(ii) reference to 1.4 solar mass (Chandrasekhar limit for white dwarfs);
if Betelgeuse blows away sufficient mass (in the supernova stage);
and is left with a core mass below the Chandrasekhar limit;
the core can form a white dwarf ***[3]***

(d) the (outer layers of the star) undergo a (periodic) expansion and contraction;
which produces a (periodic) variation in its luminosity/apparent brightness;
the (average) luminosity depends on the period of variation;
by measuring the period, the luminosity can be found;
by then measuring its apparent brightness, its distance from Earth can be found; ***[5]***

E2. (a) critical density is the density for which the universe stops expanding;
after an infinite amount of time; ***[2]***

(b) radius of the universe



(i) the time corresponding to where the two lines touch; *(labelled N on the time axis or the graph)* ***[1]***

(ii) a slightly curved line between the dotted line and the closed universe line; ***[1]***
(labelled F)

(iii) a slightly curved line between the dotted line and the flat universe line; ***[1]***
(labelled O)

Allow an accelerating universe graph labelled either For O.

E3. (a) the recessional speed of galaxies is proportional to their distance from Earth/us/ each other / $v = H_0 d$ (with terms defined); ***[1]***

(b) there is a large uncertainty in the measurement of galactic distances / it is difficult to accurately determine galactic distances; ***[1]***

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

$= \left(3\times10^8 \times \dfrac{10}{490} = \right) 6.1\times10^3\ \text{km s}^{-1}$;

$d = \dfrac{v}{H}\left(= \dfrac{6100}{70}\right) = 87\ \text{Mpc}$; ***[3]***

Option F — Communications

F1. (a) change of carrier frequency depends on amplitude of signal;
the (carrier) frequency increases as the signal displacement/amplitude increases / *vice versa*; ***[2]***

(b) (i) 185 and 195 kHz;
190 kHz; ***[2]***

(ii) difference on frequencies 135 kHz;
division by bandwidth to get 13/14; ***[2]***
*Award **[2]** for bald correct answer.*

(c) *block B*: tuning circuit;
explanation: wide range of em radiation arrives at aerial;
tuning circuit selects frequency of station required;

block C: demodulator;
explanation: separates carrier from signal wave / strips negative-going signal away / rectifies signal; ***[5]***

F2. (a) signals (A to C) are sampled sequentially;
sample time much less than time in between samples;
each sample transmitted (in series) along fibre in gaps between other samples;
re-combined in correct order at end of fibre; ***[3 max]***

(b) $\frac{I}{I_0} = 10\lg\left[\frac{25\times10^{-3}}{4\times10^{-19}}\right](=168)$;
$\frac{168}{1.8}$;
93 km; ***[3]***

(c) time between samples $= \frac{1}{32000}\left(=3.125\times10^{-5}\text{ s}\right)$;
so as each sample takes 5×10^{-8} s there will be space for $\left(\frac{3.125\times10^{-5}-50\times10^{-9}}{5\times10^{-8}}\right) = \frac{3.12\times10^{-5}}{5\times10^{-8}}$;
624 channels $\approx$ 620 channels; ***[3]***

allow

$\frac{3.125\times10^{-5}}{5\times10^{-8}}$ ***or*** $\frac{3.13\times10^{-5}}{5\times10^{-8}}$
$=625\approx620$ channels ***or*** $=626\approx630$ channels;

F3. (a) $1+\frac{800}{100}$;
9; ***[2]***

(b) (i) op-amp has a (very) large gain;
since output is finite;
the pd between X and Y has to be very small, essentially zero; ***[3 max]***

(ii) op-amp has a very high input resistance so no charge/current flows into inverting input/the two resistances are (essentially) in series; ***[1]***

F4. (a) communicates with base stations;
monitors signal strength from base stations;
selects base station with strongest signal;
allocates frequencies to cells;
connects to Internet/PSTN; ***[3 max]***

(b) any sensible environmental issue related to cellular exchange itself *e.g.* antenna attached to exchange gives visual pollution/electromagnetic pollution to people living near cellular exchanges; ***[1]***

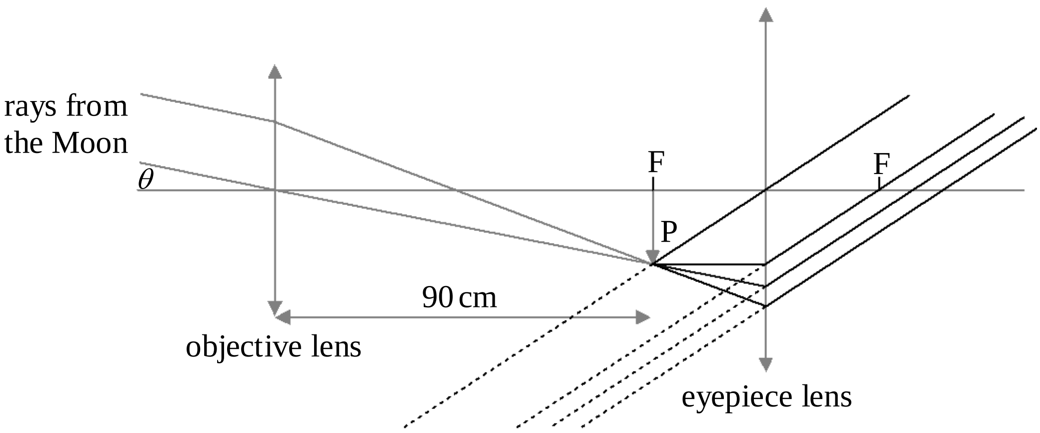
Option G — Electromagnetic waves

G1. (a) oscillating/vibrating electric and magnetic fields;
at right angles to each other;
at right angles to the direction of propagation/energy transfer of the wave/ velocity/transverse;
can travel through vacuum; ***[2 max]***
*Award **[2]** for a clearly drawn, correctly labelled diagram i.e. E and B fields at right angles to each other and at right angles to the direction of propagation.*

(b) electrons that oscillate/accelerate/move on curved paths;
electrons making transitions between energy levels; ***[2]***
Accept two specific instances of electrons being accelerated/decelerated e.g. electrons hitting metal target or electrons moving in magnetic fields.

G2. (a) (i) F at P and second F at the same distance to the right of the eyepiece; *(judge by eye)* ***[1]***

(ii)



first construction line or ray; *(judge by eye)*
second construction line or ray;
extension of these to the left as parallel lines; ***[3]***

(b) (i) $d = f_0 \tan\theta \approx f_0\theta$;
$d = 90 \times \tan(8.7\times10^{-3}) = 0.78\,\text{cm}$; ***[2]***

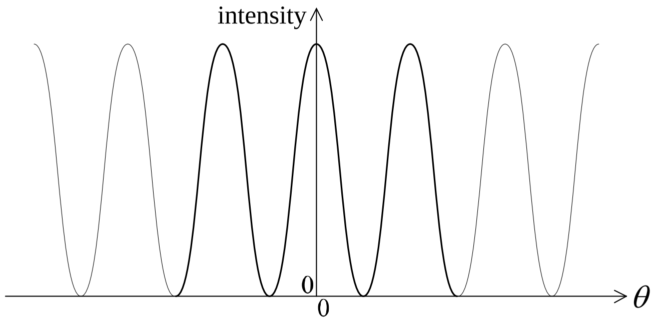
(ii) angular magnification is $M = \left(-\frac{f_0}{f_e} = \right)(-)3$;
hence $\theta' = -3\theta = (-)0.026\,\text{rad}$; ***[2]***

or

$\theta' = \frac{0.78}{30}$;
$\theta' = (-)0.026\,\text{rad}$;

G3. (a) (i) diffraction; ***[1]***

(ii) correct general shape $\left(\cos^2\theta\right)$ touching the horizontal axis;
constant amplitude;
equally spaced maxima; ***[3]***
Diagram must have at least three fringes.
*Award **[0]** for single slit diffraction pattern.*



*Award **[3]** for correct graph that shows modulation by single slit diffraction.*

(iii) $\text{MQ} = \frac{1}{2}\frac{\lambda D}{d}$;

$\text{MQ} = \left(\frac{650\times10^{-9}\times1.80}{2\times0.12\times10^{-3}} = \right) 4.9\,\text{mm}$; ***[2]***

(b) the energy gets redistributed/the total energy in the pattern is the same as the total emitted energy;
the energy that would have appeared at minima now appears at the maxima; ***[2]***

G4. (a) lattice/atoms/ions scatter/reflect incident beam;
mention of interference;
interference is constructive when the path difference is an integer multiple of the wavelength; ***[3]***

(b) $2d\sin\theta = \lambda \Rightarrow d = \dfrac{\lambda}{2\sin\theta}$;

$d = \left(\dfrac{8.24\times10^{-10}}{2\times\sin 11.2^{\circ}} =\right) 2.1\times10^{-9}\text{ m}$; ***[2]***

*Award **[0]** for use of* $d\sin\theta = n\lambda$.

G5. (a) the path difference (at normal incidence) is $2t$;
since there is phase change of π at both surfaces there is destructive interference if the path difference is half integral multiple of the wavelength;
and so $2t = \left(m + \dfrac{1}{2}\right)\lambda$ ***[2]***

(b) (i) $\lambda = \dfrac{\lambda_{\text{air}}}{n} = \dfrac{640}{1.38}$;
$= 464\,\text{nm}$ ***[1]***

(ii) $m = 0 \Rightarrow t = \dfrac{\lambda}{4}$;

$t = \left(\dfrac{464}{4} =\right) 116\,\text{nm} \approx 120\,\text{nm}$; ***[2]***

Option H — Relativity

H1. (a) the speed of light in a vacuum is the same for all inertial observers/observers in uniform motion; ***[1]***

(b) (i) ground observer measures a zero proper time interval for the two arrivals;
all other observers measure a time interval of $\gamma \times 0 = 0$;
hence the arrivals are simultaneous for all observers, including rocket ***[2]***
*Award **[1]** for statement that "events that are simultaneous for one observer and occur at the same place are simultaneous for all observers".*

(ii) according to the rocket observer, the ground observer moves towards the signal from tree L and away from the signal from tree R;
since the signals move at the same speed and they arrive at the same time according to the rocket observer;
signal from tree R must have been emitted first ***[2]***

H2. (a) (i) 9.1×10^{-7} s; ***[1]***

(ii) the gamma factor is $\gamma = \left(\frac{1}{\sqrt{1-0.920^2}} = \right) 2.55$;

and so $t' = \left(\frac{9.1 \times 10^{-7}}{2.55} = \right) 3.5 \times 10^{-7}$ s; ***[2]***

(b) 98 (m); ***[1]***
Allow ECF from gamma factor in (a)(ii).

(c) $u' = \left(\frac{u - v}{1 - \frac{uv}{c^2}} = \right) \frac{0.985c - 0.920c}{1 - \frac{0.985c \times 0.920c}{c^2}}$;

$u' = 0.693c$; ***[2]***

(d) both observers measure different values for the half-life;
and the two half-lives are related by the gamma factor; ***[2]***

H3. (a) $v = 0.96\text{c}$ when $E_{\text{K}} = 360\,(\text{MeV})$;

calculation of gamma factor $\gamma = \dfrac{1}{\sqrt{1-0.96^2}} = 3.571$;

so that $m = \dfrac{E_{\text{K}}}{(\gamma-1)c^2} = \dfrac{360}{2.571\text{c}^2}$;

$m = 140\,\text{MeV}\,\text{c}^{-2}$; ***[4]***

(b) change in kinetic energy is $360 - 40 = 320\,\text{MeV}$;

so voltage required is $320\,\text{MV}$; *(unit needed)* ***[2]***

MV needed for second marking point.

H4. (a) combined use of $p = \gamma m v$ and $E = \gamma m c^2$;

eliminate the mass and gamma factor by, for example, dividing to get $\dfrac{p}{E} = \dfrac{v}{c^2}$;

to get the result ***[2]***

Accept going backwards from given result to reach correct formulae.

(b) for a particle with zero rest mass, $E = pc$;

and so $v = \left(\dfrac{pc^2}{pc} = \right)c$; ***[2]***

Award ***[1]*** *for "zero rest mass particles are photons and so* $v = c$*".*

H5. (a) inertial/acceleration effects are indistinguishable from gravitational effects / a freely falling frame of reference in a gravitational field is equivalent to an inertial frame of reference / an accelerating frame of reference in outer space is equivalent to a frame of reference at rest in a gravitational field; ***[1]***

(b) *1*: $f = f_0$;
because the frame of reference is equivalent to an inertial frame of reference;

2: $f < f_0$;
the frame of reference is equivalent to a frame of reference at rest in a gravitational field and so light is gravitationally red-shifted; ***[4]***

or

$f < f_0$;
observer at T will observe the source as though it was moving away from him and so will measure a Doppler red-shifted frequency;

(c) the signal from satellite X will arrive after that from satellite Y / there will be a time delay in the arrival of signal X;
because the X signal undergoes gravitational time dilation/bends/curves (in the field of the Sun); ***[2]***

Option I — Medical physics

I1. (a) $\mathrm{IL} = 10\lg\left(\frac{\mathrm{I}}{I_0}\right)$ ***or*** $\lg\left(\frac{\mathrm{I}}{I_0}\right)$;
dB/decibel / B/bel; *(unit must match definition)*
$I_0 = 1\times10^{-12}\ \mathrm{W\,m^{-2}}$; ***[3]***

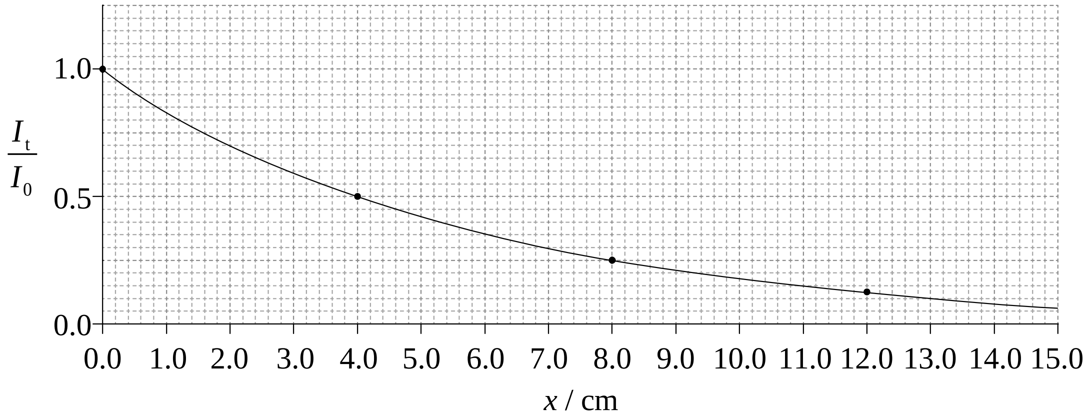
(b) $\text{intensity} = \frac{1.5\times10^{-5}}{2.4\times10^{-5}}(=0.625)$;
$\mathrm{IL} = 10\lg\left(\frac{0.625}{1\times10^{-12}}\right)$;
$= 118 \approx 120\ \mathrm{dB}$; ***[3]***

(c) *short-term*: this is very close to the pain threshold/will cause ringing in the ear/tinnitus;
long-term: (prolonged exposure) will reduce sensitivity of ear / reduce high frequency response / *OWTTE*; ***[2]***

I2. strong field causes protons (in the body) to precess/align with the field;
gradient magnetic field applied so that magnetic field at every point in the body is different;
radio frequency radiation directed at the body excites protons (to a higher energy state);
frequency emitted (by de-exciting protons) depends on magnetic field;
frequency determines point of emission (since different parts of the body correspond to different frequency);
intensity of radiation/relaxation times depend on type of tissue (so that contrast can be achieved); ***[4 max]***

I3. (a) smooth curved decay line beginning at $\frac{I_t}{I_0}=1$ when $x=0$;

passing through other three points as shown;



[2 max]

(b) $\mu=\frac{\ln 2}{4}$;

0.17cm^{-1}; ***[2]***

Watch for alternative correct answers such as 17m^{-1}.

(c) $e^{-\mu x}$ smaller / $e^{\mu x}$ is larger;

μ larger; ***[2]***

or

it has a shorter half value thickness;

and so μ larger;

(d) stomach tissue has similar attenuation coefficient to nearby tissue (so does not show up on X-ray);

barium absorbs X-rays well (and lines the stomach after drinking);

barium allows stomach walls to show as contrast; ***[3]***

I4. (a) (the time taken for the activity to reduce by half) taking into account both physical and biological removal of activity from the body / *OWTTE*; ***[1]***

(b) effective half life $= \left[\frac{1}{8}+\frac{1}{12}\right]^{-1} = 4.8\,\text{days}$;

$\lambda = \frac{\ln 2}{4.8} = 0.144$;

$\frac{A}{A_0} = e^{-\lambda t} = e^{-0.144\times 11}$;

0.20; ***[4]***

(c) activity will drop more quickly/exposure time to radiation is less;
so patient not at risk for so long; ***[2]***

(d) mention of lead / mention of shielding (steel, iron, concrete);
mention of distance; ***[2]***

Option J — Particle physics

J1. (a) the spin number of a boson is an integer value;

the spin of the kaon can be $\frac{1}{2}+\frac{1}{2}=1$ ***or*** $\frac{1}{2}-\frac{1}{2}=0$; ***[2]***

Reference to either 0 or 1 is fine, both are not needed.

(b) (i) *X*: anti-strange quark / $\bar{s}$;
Y: antimuon / μ^{+}; ***[2]***

(ii) the process violates strangeness number conservation;
only the weak interaction allows this violation; ***[2]***

or

the decay of the kaon involves a neutrino;
any decay involving the neutrino must take place by the weak interaction;

(iii) *name*: W (boson);
sign: positive; ***[2]***

(iv) $R=\frac{h}{4\pi mc}=\frac{6.63\times10^{-34}}{4\pi(1.4\times10^{-25})\times3\times10^{8}}$;

$R=1.3\times10^{-18}$ m; ***[2]***

(v) so that <u>muon</u> lepton number is conserved; ***[1]***

J2. (a) (i) there is an electric field between each pair of tubes;
the proton experience a force every time they enter the region between the tubes; ***[2]***

(ii) the polarity of a tube must change to negative just as proton emerges;
therefore faster protons must spend the same time in a tube as slower protons;
so tubes get longer ***[2]***

(b) (i) positive in order to satisfy electric charge conservation; ***[1]***

(ii) baryon in order to satisfy baryon number conservation/contains 3 quarks; ***[1]***

(iii) $E_{\mathrm{A}} = \sqrt{2\times150\times5.2\times10^{3}+938^{2}+140^{2}} = 1534\,\mathrm{MeV}$;
$M_{\mathrm{X}}c^{2}+494 = 1534$;
$M_{\mathrm{X}} = 1040\,\mathrm{MeV\,c^{-2}}$; ***[3]***

(c) (i) the de Broglie wavelength is $\lambda = \dfrac{6.63\times10^{-34}}{2.7\times10^{-18}} = 2.5\times10^{-16}\,\mathrm{m}$;
this is less than the nucleon size so nucleons can be resolved; ***[2]***
Argument required for second mark.

(ii) but it is greater than the quark size so quarks cannot be resolved; ***[1]***

(d) deep inelastic scattering experiments measure the (fraction of) momentum carried by electrically charged constituents of hadrons;
this is less than the total momentum of the hadron indicating the presence of neutral constituents; ***[2]***

J3. (a) the temperature corresponding to the energy of $3\times10^{-11}\,\mathrm{J}$ is $\dfrac{3}{2}kT = 3\times10^{-11} \Rightarrow T = 1.4\times10^{12}\,\mathrm{K}$;
since $\lg T = 12.2$ we get $\lg t = -10$;
and so $t \approx 10^{-10}\,\mathrm{s}$; ***[3]***

(b) the Higgs is the only undiscovered particle of the standard model;
the discovery would help to verify standard model / failure to discover it would necessitate a change in the model;
the Higgs is responsible for giving mass to particles / is linked to the problem of mass so its discovery would shed light on the problem of mass; ***[2 max]***