M09/4/PHYSI/HP3/ENG/TZ1/XX/M+

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MARKSCHEME

May 2009

PHYSICS

Higher Level

Paper 3

18 pages

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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 **no**t 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. 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.

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

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*

Option E — Astrophysics

E1. (a) apparent magnitude is a measure of how bright a star appears from Earth;
absolute magnitude is a measure of how bright a star would appear from a distance of 10 pc; ***[2]***

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

(ii) stars differ by $\Delta M = 16$;
for $\Delta M = 1$ we have a ratio of luminosities by a factor of $\sqrt[5]{100} \approx 2.51$ ***or*** 2.5;
so $\frac{L_A}{L_E} = \left(\sqrt[5]{100}\right)^{16} \approx 2.5 \times 10^6$ ***or*** 2.3×10^6; ***[3]***

Award ***[2 max]*** *for use of apparent magnitude difference and an answer for the ratio of* 6.3×10^5.

(iii) $d = \left(10 \times 10^{\frac{m-M}{5}}\right)$;
$\approx 10 \times 10^{\frac{3.5}{5}}$;
≈ 50 pc ***[2]***

(c) $\frac{L_M}{L_A} = 1$;
$1 = \frac{\sigma 4\pi R_M^2 T^4}{\sigma 4\pi R_A^2 (5T)^4}$;
$\frac{R_M}{R_A} = 25$; ***[3]***

(d) it has to be hot star/a B star;
with low luminosity/high <u>absolute</u> magnitude;
hence EG129; ***[3]***

E2. (a) $T = \frac{2.9 \times 10^{-3}}{1.07 \times 10^{-3}}$;
$T = 2.7\text{ K}$; **[2]**
Accept wavelengths in the range 1.05 to 1.10 for a temperature range 2.64 to 2.76 K.
Award ***[0]*** *for bald answer.*

(b) according to the Big Bang model the temperature of the universe (and the radiation it contained) in the distant past was very high;
the temperature falls as the universe expands and so does the temperature of the radiation in the universe; **[2]**

(c) (Hubble's law shows that) the universe is expanding;
therefore in the distant past the universe must have been a very small/hot/dense point-like object;

or

Doppler shift of spectral lines;
indicates galaxies moving away so in the past they were close to each other; **[2]**

E3. (a) the largest mass a neutron star can have (2-3 solar masses) / core mass which if exceeded leads to a black hole; **[1]**

(b) (i) the star will evolve to become a red super giant;
nuclear reactions involving elements heavier than hydrogen take place / nuclear reactions produce heavier elements up to iron;
will then explode in a supernova;
<u>the final mass of the core/remnant of the star will be less than the Oppenheimer-Volkoff limit/less than a few solar masses/less than 3 solar masses</u>; **[2 max]**
To award ***[2]*** *the last marking point is essential.*

(ii) neutron (degeneracy) pressure; **[1]**

(c) (i) $l = kM^{2.5}$;
so $\frac{l_{EtaC}}{l_{sun}} = \left(\frac{M_{Eta}^{2.5}}{M_{sun}^{2.5}}\right) = \left(100^{2.5}\right) = 10^5$; **[2]**

(ii) Eta Carinae is producing energy disproportionately more (relative to the available mass) and hence will spend less time (10^5 less) on the main sequence / *OWTTE*; **[1]**
Award ***[0]*** *for bald answer.*

E4. (a) distant galaxies move <u>away</u> from Earth;
with a speed proportional to their distance (from Earth); **[2]**

(b) because the motion of nearby galaxies is much more affected by their mutual gravitational interactions rather than the expansion of the universe; **[1]**

Option F — Communications

F1. (a) (i) 3.0 MHz; ***[1]***

(ii) 40 kHz; ***[1]***

(iii) 80 kHz; ***[1]***

(b) $\left(\frac{320}{80}\right) = 4$; ***[1]***

F2. (a) P: analogue signal is sampled at the sampling frequency and stored;
Q: each sample is converted into a binary word (in the diagram a word of 4-bits);
R: parallel to serial converter / *OWTTE*;
S: the digital signal converted into an analogue signal; ***[4]***

(b) (i) $15 = \left(1\times 2^3 + 1\times 2^2 + 1\times 2^1 + 1\times 2^0\right) = 1111$; ***[1]***
*Award **[1]** for bald answer.*

(ii) bit-rate = $f_{\text{sampling}} \times$ bits per word

sampling frequency is $\left(\frac{1}{0.01\times 10^{-3}}\right) = 100$ kHz;

$100 \times 4 = 400$ kHz; ***[2]***

(c) *advantage*:
signal can be reconstructed more accurately from its samples;

disadvantage:
more memory/storage space is required/increased bit-rate required; ***[2]***

F3. (a) *attenuation*:
impurities in the glass core of the fibre;

dispersion:
material dispersion *i.e.* dependence of refractive index on wavelength/
modal dispersion *i.e.* rays of light of the same wavelength that follow different paths along the fibre; ***[2]***

(b) (i) loss of $5.4 \times 2.8 = 15\ \text{dB}$;
$\left(-15 = 10\log\frac{80}{P} \Rightarrow\right) P = 2.5\ \text{mW}$; ***[2]***

(ii) 15 dB; ***[1]***
Watch for e.c.f. from (i).

(c) after amplification the signal and noise powers are

$\left(15 = 10\log\frac{P'_{\text{signal}}}{P_{\text{signal}}} \Rightarrow\right) P'_{\text{signal}} = 10^{1.5} P_{\text{signal}}$ and $P'_{\text{noise}} = 10^{1.5} P_{\text{noise}}$;

and so the new signal-to-noise ratio is $10\log\frac{P'_{\text{signal}}}{P'_{\text{noise}}} = 10\log\frac{P_{\text{signal}}}{P_{\text{noise}}} = 20\ \text{dB}$; ***[2]***

*To award **[2]** accept answers that state that both signal and noise get amplified by the same amount and so SNR remain the same.*

F4. (a) the sign of the output voltage is the same as that of the input voltage; ***[1]***

(b) (i) $G = \left(1 + \frac{90}{10} =\right) 10$; ***[1]***

(ii) $V_{\text{out}} (= GV_{\text{in}} = 10 \times 2.0) = 20\ \text{mV}$; ***[1]***

(c) op-amp has a high input resistance and so takes little current;
(open loop) gain is very large so potential difference between non-inv input and inv input is (effectively) zero;
i.e. $V_{out}=V_{in}$;
So G=1 ***[3]***

(d) (i) 3.0V; ***[1]***

(ii) the resistance between A and B is smaller than 2 MΩ / the voltmeter draws current; ***[1]***

(iii) the voltmeter reads the output voltage of the amplifier and the input voltage is the potential difference to be measured;
the two are equal since the gain is 1; ***[2]***

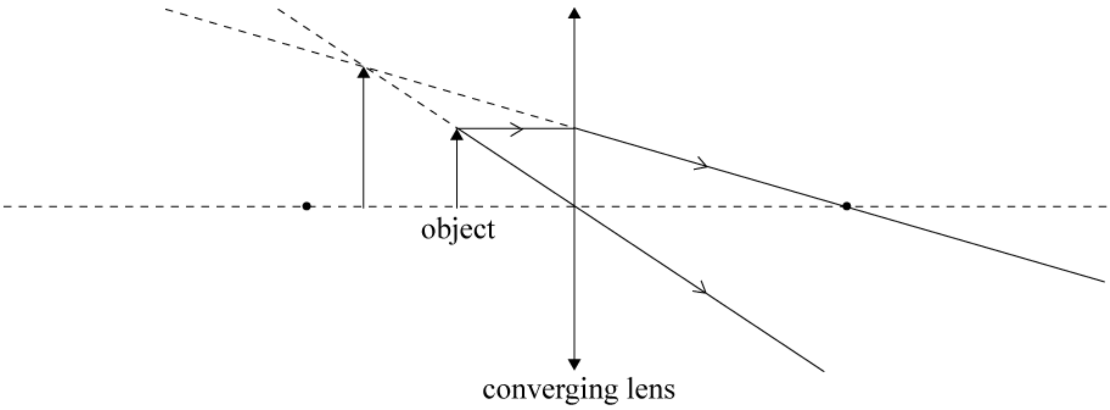
Option G — Electromagnetic waves

G1. *blue sky*:
(the colour of the sky in the course of a clear day) is determined by the colour that scatters the most;
and that the colour is blue (since the amount of scattering is proportional to $\frac{1}{\lambda^4}$); ***[2]***

red sky:
during sunset light has to travel a very long distance through the atmosphere;
most of the blue has been scattered away, leaving behind red; ***[2]***
No ECF if first marking point is wrong.

G2. (a) the nearest point at which the human eye can focus comfortably/without straining; ***[1]***

(b) *Award **[1]** for each correct ray.* ***[2]***



Accept ray passing through left focal point and emerging parallel to the principal axis.
Arrows are not required on the rays.

(c) (i) $\frac{1}{u} = \frac{1}{9.0} - \left[-\frac{1}{25}\right]$;
$u = 6.6\text{ cm}$; ***[2]***

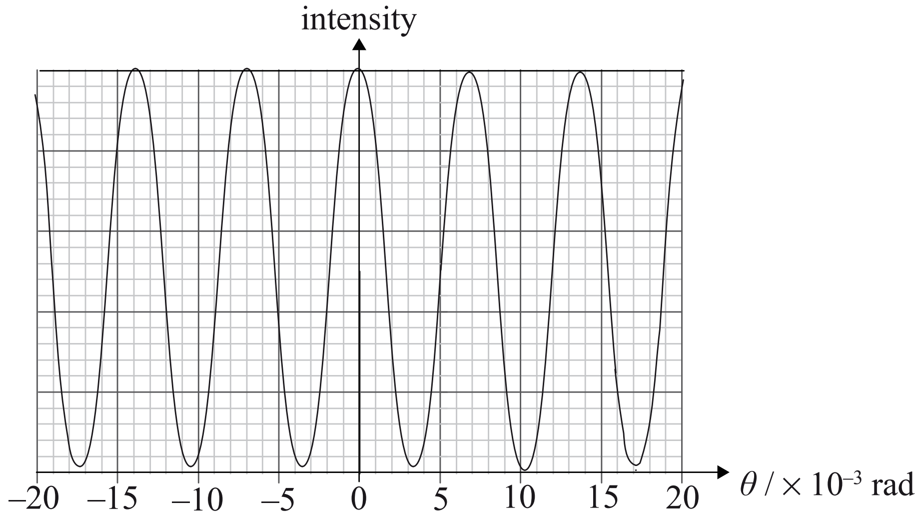
(ii) $M = \left(1 + \frac{25}{9.0} = \right) 3.8$; ***[1]***
Accept answer that uses lateral magnification which, in this case, gives the same answer.

(d) aberrations (spherical/chromatic) increase; ***[1]***

G3. (a) (i) at $\theta = 0$ the path difference (between light from the two slits) is zero;
and so constructive interference takes place; ***[2]***

(ii) $\sin\theta = \frac{\lambda}{d} = \frac{6.80\times10^{-7}}{1.13\times10^{-4}}$;
6.02×10^{-3} rad; ***[1]***

(iii) spacing of maxima by 6.02×10^{-3} rad;
equal heights of maxima / maxima decreasing to the sides due to diffraction effects;
maximum at zero; ***[3]***



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

(ii) stays the same; ***[1]***

(iii) gets smaller; ***[1]***

G4. (a) (i) the difference in energy between the ground state and an excited state;
is more than the <u>maximum</u> kinetic energy of an accelerated electron; ***[2]***

(ii) photons are produced when electrons radiate as they are rapidly decelerated/accelerated/collide with lattice ions/atoms;
the photons of wavelength 2.0×10^{-10} m are produced when an electron gives <u>all</u> its (kinetic) energy to a <u>single</u> photon/when the (kinetic energy) is transferred in a <u>single</u> collision; ***[2]***

(iii) $eV = \dfrac{hc}{\lambda}$

$V = \dfrac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{1.6 \times 10^{-19} \times 2.0 \times 10^{-10}}$;

$V = 6.2$ kV; ***[2]***

(b) (i) $\theta_1 = \theta_2$;
the path difference (between two scattered beams) is zero/in phase; ***[2]***

(ii) $2d \sin\theta = \lambda$

$d = \dfrac{4.20 \times 10^{-10}}{2 \sin 34.5^{\circ}}$;

$d = 3.7 \times 10^{-10}$ m; ***[2]***

Option H — Relativity

H1. (a) (i) to measure the speed of the Earth in its orbit/relative to the ether / to detect the ether / to find an absolute reference frame; ***[1]***

(ii) $c - v$; ***[1]***

(b) (i) a shift of the interference pattern (horizontally) / a different interference pattern; ***[1]***

(ii) no shift (within experimental error); ***[1]***

(iii) the speed of light is constant for all inertial observers / the ether does not exist / there is no absolute reference frame; ***[1]***

H2. (a) the time interval between two events that occur at the <u>same point in space</u>; ***[1]***

(b) Hermann measures a zero time difference between the arrival of the light pulses;
because these occur at the same point in space this is a proper time interval;
so any other observer will measure a time interval of $= \gamma \times 0 = 0$ *i.e.* events will be simultaneous; ***[3]***
Award ***[2 max]*** *for answers based on "events are simultaneous in one frame and occurring at the same point therefore are simultaneous for everybody".*

H3. (a) (i) $\left(\dfrac{52\text{ ly}}{0.80c}\right) = 65\text{ y}$; ***[1]***

(ii) $\left(\dfrac{52\text{ ly}}{\frac{5}{3}}\right) = 31.2\text{ ly} \simeq 31\text{ ly}$; ***[1]***

(iii) time to reach planet according to spacecraft is $\left(\dfrac{31.2\text{ ly}}{0.80c}\right) = 39\text{ y}$;

so Amanda is 59 years old;

or

leaving earth and arriving at planet occur at the same point for Amanda;

so time taken is $\dfrac{65}{5/3} = 39$ y, hence age is 59 years old; ***[2]***

(b) let the required time be denoted by T

signal reaches Earth after travelling a distance of cT;

this distance is 31.2 ly plus the distance travelled by earth in time T *i.e.* $31.2 + 0.80cT$;

$cT = 31.2 + 0.80cT \Rightarrow T = 156$ yr;

*Award **[2]** for use of ct = 0.80 ct + 52 and an answer for 260 years.*

or

the events "spacecraft leaves Earth" and "signal arrives at Earth" are separated by a proper time interval for the earth observers;

this time interval is 65 + 52 = 117 yr;

so spacecraft observers measure a time interval of $\dfrac{5}{3} \times 117 = 195$ yr so signal takes $195 - 39 = 156$ yr to arrive on Earth; ***[3]***

H4. (a) the rest energy corresponds to the energy when $v = 0$ and (is 490 MeV and so rest mass is 490 MeVc^{-2}); ***[1]***
Do not penalize units.

(b) change in total energy after acceleration is $(1570 - 490) = 1080\,\text{MeV}$;
and so p.d. is 1080 MV; ***[2]***
Do not penalize units.

(c) (i) muon and neutrino have equal and opposite momenta;
conservation of energy gives $490 = pc + \sqrt{105^2 + p^2c^2}$;
solving for p algebraically ***or*** using a GDC ***or*** using a substitution $\Rightarrow p = 234\,\text{MeVc}^{-1}$ ***[2]***

(ii) $E = \sqrt{105^2 + 234^2}$;
$E = 256\,\text{MeV}$;
$E_K (= 256 - 105) = 151\,\text{MeV}$; ***[3]***

H5. (a) the distance from the centre of a (non rotating) black hole where the escape speed is the speed of light / distance from singularity to event horizon / distance from which light can just not escape; ***[1]***
Do not accept the formula unless symbols are all defined.

(b) (i) gravitational redshift / gravitational time dilation; ***[1]***

(ii) realization that the time dilation factor is $\left(\frac{4.5\times10^{14}}{3.0\times10^{14}} =\right)1.5$;
and so one pulse is received every 3 seconds; ***[2]***

(iii) $\sqrt{1 - \frac{6.7\times10^4}{r}} = \frac{1}{1.5}$;

solving for r to give $r = (1.8R_S) = 1.2\times10^5$ m; ***[2]***

Option I — Medical physics

I1. (a) (i) the maximum force on the eardrum is $F = 3.0\times10^{-2}\times A(=1.26\times10^{-6}\,\text{N})$;

the average power is

$$P = \frac{F_{\max}v_{\max}}{2} = \left(\frac{3.0\times10^{-2}\times A\times12\times10^{-5}}{2} = \right)1.8\times10^{-6}\times A(=7.56\times10^{-11}\,\text{W});$$

intensity is

$$I = \frac{P}{A} = \frac{1.8\times10^{-6}\times A}{A}\,\text{W m}^{-2} \quad \left(= \frac{7.56\times10^{-11}}{42\times10^{-6}} = 1.8\times10^{-6}\,\text{W m}^{-2}\right);$$

$I = 1.8\times10^{-6}\,\text{W m}^{-2}$ **[3]**

Do not insist on algebraic expressions. Numerical answers are sufficient.

(ii) $I.L. = \left(10\log\frac{1.8\times10^{-6}}{1.0\times10^{-12}}\right) \approx 63\,\text{dB}$; **[1]**

(b) the force transmitted is 1.5 times larger $= 42\times3\times10^{-2}\times1.5$;

and so $\Delta P = \frac{42\times3\times10^{-2}\times1.5}{3.2} = 0.59\,\text{Pa}$; **[2]**

(c) the vibrations of the eardrum force the ossicles (in the middle ear) to vibrate;
and these in turn transmit the vibrations to the fluid in the inner ear through pressure exerted on the oval window (by the stirrup); **[2]**

I2. (a) (i) sound whose frequency is above 20 kHz/above the upper limit of hearing of a human being; ***[1]***

(ii) alternating voltage is applied to a crystal;
forces the crystal to vibrate emitting ultrasound; ***[2]***

(b) $Z = \left(\rho c = 2800 \times 1.5 \times 10^3 = \right) 4.2 \times 10^6 \left(\mathrm{kg\,m^{-2}\,s^{-1}}\right)$; ***[1]***

(c) (i) the brain is made of uniform tissue *i.e.* $\underline{Z_1 = Z_2}$;
and so no features can be distinguished since no reflection can take place; ***[2]***

(ii) $\frac{I_R}{I_0} = \left(\frac{430 - 1.6 \times 10^6}{430 + 1.6 \times 10^6}\right)^2$;
$\frac{I_R}{I_0} = 0.9989 \approx 1.0$; ***[2]***

(iii) most of the ultrasound is reflected when the impedances of the two media are different;
the gel makes sure that the ultrasound enters tissue from a medium of approximately the same impedance; ***[2]***

(d) (i) time to travel from transducer to stomach is $\frac{50}{2} = 25\,\mu\mathrm{s}$;
distance $\left(1600 \times 25 \times 10^{-6}\right) = 4.0 \times 10^{-2}\,\mathrm{m} = 4.0\,\mathrm{cm}$; ***[2]***

(ii) B scans produce two dimensional images whereas A scans are one dimensional;
B scans provide real time "video" images; ***[2]***

I3. (a) (i) injected intravenously / swallowed in liquid form / as a capsule; ***[1]***

(ii) iodine concentrates in the thyroid; ***[1]***

(iii) cancerous cells are more easily killed (especially when they are dividing);
the rate of repair of cancerous cells is slower; ***[2]***

(b) (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]***

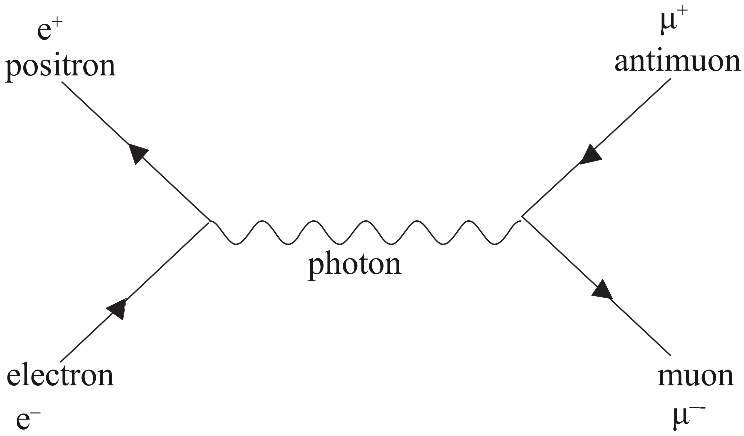
(ii) $\left(\frac{1}{8} + \frac{1}{12} = \frac{1}{T} \Rightarrow\right) T = 4.8$ days; ***[1]***

(iii) (two half lives must go by *i.e.*) 9.6 days ≈ 10 days; ***[1]***

Option J — Particle physics

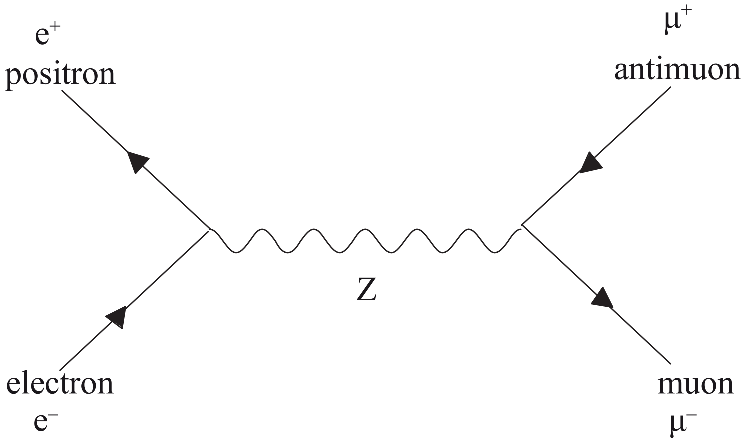
J1. (a) electric charge must be conserved at each vertex;
and both the photon and the Z are neutral; ***[2]***

(b) (i)



[1]

(ii)



[1]

*Award **[0]** if arrow directions are not consistent with labels.*

(iii) *virtual particle in (i)*: photon;
virtual particle in (ii): Z;
} *need both correct to award the mark* ***[1]***

(c) because the strength of the electromagnetic interaction is not the same/is greater than the strength of the weak interaction;

or

the weak interaction diagram contains a very heavy intermediate particle as opposed to a massless particle in the electromagnetic interaction; ***[1]***

(d) the energy needed to create the muons at rest is $2 \times 105 = 210$ MeV;
$210^2 = 2 \times 0.511 \times E + 2 \times 0.511^2$;
giving $E = 43$ GeV; ***[3]***

J2. (a) (i) charged particles (moving through hydrogen near its boiling point) ionize atoms;
visible bubbles appear along path of the particle; ***[2]***

(ii) the sign of the electric charge by seeing which way the particle bends in the magnetic field;
the momentum by measuring the radius of the circular path (and knowing that most particles have a charge equal to $\pm$ e);
the rate of energy loss from the density of the bubbles; ***[2 max]***

(b) no photographs need to be taken (whose analysis is extremely difficult and time consuming);
there is no "dead time" as in a bubble chamber in between successive photographs;
the information is digital and so can be processed easier; ***[2 max]***

J3. (a) (i) circle around the point with $Q = S = 0$; ***[1]***

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

(b) weak;
the reaction violates strangeness;
the other interactions conserve strangeness/only the weak interaction violates strangeness;

or

weak;
the reaction changes quark flavour;
and only the weak does that; ***[3]***

J4. (a) the average kinetic energy of the quarks was very high because the temperature was very high;
the quarks moved with too much kinetic energy that prevented them from binding / the average kinetic energy was greater than the binding energy of the nucleons; ***[2]***

(b) $\frac{3}{2}(1.38\times10^{-23})\times T = 50\times10^{6}\times1.6\times10^{-19}$ J ;

$T = \left(\frac{2\times50\times10^{6}\times1.6\times10^{-19}}{3\times1.38\times10^{-23}}\right) = 3.9\times10^{11}$ (K) $\approx 4\times10^{11}$ K ; ***[2]***

(c) in the early universe/when the temperature was very high particles collided with antiparticles to create photons and the photons materialized into particle-antiparticle pairs;
As the temperature dropped, the second process became impossible and so the universe was left with (the small number of excess particles); ***[2]***

(d) there has been a long attempt to provide a quantum theory of gravitation;
but all theories based on point particles have failed; ***[2]***

(e) the extra dimensions are supposed to be curved into a compact/closed/finite/Calabi-Yau space;
whose typical linear size is unobservably small; ***[2]***