N09/4/PHYSI/HP3/ENG/TZ0/XX/M+

International Baccalaureate®
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MARKSCHEME

November 2009

PHYSICS

Higher Level

Paper 3

18 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 **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. 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) (i) gives the relative (visual) brightness of stars <u>as seen from Earth</u>;
e.g. a magnitude 1 star is 100 times brighter than a magnitude 6 star; ***[2]***
*To award **[2]** the idea of a relative scale must be clear.*

(ii) the apparent magnitude a star would have if it were 10 pc from Earth; ***[1]***

(b) (i) $\log \frac{d}{10} = \frac{m-M}{5}$;
$=1.03$;
$d = 10 \times 10^{1.03}$;
$= 108\,\text{pc}$ ***[3]***
Accept answer based on substitution for $d = 108$.

(ii) $L = 4\pi d^2 b$;
$\frac{L_B}{L_{Sun}} = \frac{d_B{}^2 b_B}{d_{Sun}{}^2 b_{Sun}}$;
$L_B = 108 \times 2.05^{\;2} \times 10^{10} \times 7.00 \times 10^{-12}\, L_{Sun}$;
$= 3.43 \times 10^3\, L_{Sun}$ ***[3]***
Accept answer based on substitution $L_B = 3.43 \times L_{Sun}$.

(c) $3.4 \times 10^3 = \left[\frac{M_B}{M_{Sun}}\right]^{3.5}$;

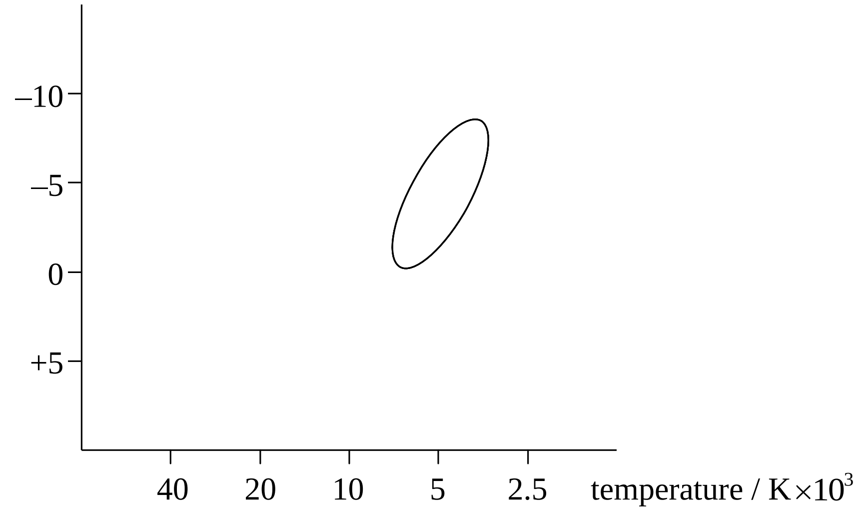
$M_B = \left[3.4 \times 10^3\right]^{\frac{1}{3.5}} M_{Sun}$; *(allow other evidence of algebraic manipulation)*
$M_B \approx 10\, M_{Sun}$ ***[2]***

(d) *Sun*: white dwarf;
Becrux: neutron star/black hole; ***[2]***

(e) (i) in the region $30 \to 50,\ -2.5 \to -5.0$; ***[1]***

(ii) line from B to region $5 \to 2,\ -5 \to -10$; ***[1]***
Do not penalize for any line after red giant position.

(f)



Cepheid as shown; ***[1]***
Judge by eye for reasonable range of magnitude and temperature.

(g) the outer layers undergo a periodic expansion and contraction/periodic fluctuations in temperature; ***[1]***

(h) period/frequency with which luminosity varies;
apparent brightness / apparent magnitude; ***[2]***

E2. (a) Newton's model assumed a uniform infinite (and static) universe;
therefore number of stars in shell is proportional to R^2;
intensity of radiation/light from shell reaching Earth is proportional to $\frac{1}{R^2}$;
since according to Newton's model such shells stretch to infinity / the sky can never be dark/will always be light / *OWTTE*; ***[4]***

(b) (i) the early universe/the universe immediately after the Big Bang was very hot/at very high temperature;
radiation in the universe corresponded to the very high temperature;
as the universe expanded it cooled down and the wavelength of the radiation increased / *OWTTE*; ***[3]***

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

$= 0.083c$ ***or*** $2.5\times10^{7}\ \mathrm{m\,s^{-1}}$;

$d = \frac{v}{H_0}$;

$= 340\,\mathrm{Mpc}$; ***[4]***

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) AM varies the amplitude (of the carrier wave) and FM varies the frequency (of the carrier wave); ***[1]***

(c) $A \rightarrow B$: constant/no change;
$B \rightarrow C$: increasing;
$C \rightarrow D$: decreasing; ***[3]***

(d) (i) $f_S = \left(\frac{1}{T} =\right) \frac{1}{1.2 \times 10^{-3}}$;
$= 830\,\text{Hz}$; ***[2]***

(ii) $f_C = \frac{2.2 \times 10^5}{1.2 \times 10^{-3}}$;
$= 180\,\text{MHz}$ ***or*** $1.8 \times 10^8\,\text{Hz}$; ***[2]***

F2. (a) (i) sampling frequency $= 10^4$ (s^{-1});
bit rate($=$number of bits $\times$ sampling frequency) $= 30\,\text{kb s}^{-1}$; ***[2]***

(ii) at $500\,\mu\text{s}$ output $= 3.6\,\text{V}$;
therefore digital output $= 111$; ***[2]***

(b) increasing the sampling frequency means smaller increments of voltage will be measured;
increasing number of bits means that that sampled voltage can be represented more accurately;
some conclusion *e.g.* the digital encoding will be a more accurate/faithful representation of the analogue signal; ***[3]***

(c) (i) $10\lg\dfrac{I}{I_0}$ where $I=$input power and $I_0 =$ output power; ***[1]***

(ii) dB loss $= (10\lg 4 =)\,6.0\,\text{dB}$;
distance $= 3.0\,\text{km}$; ***[2]***

(d) (i) (very) high input resistance;
(very) high (open loop) gain;
(very) low output resistance; ***[2 max]***

(ii) pd across $10\,\text{k}\Omega = V_{\text{in}} - 1.0 = 10^4 I$;
pd across $50\,\text{k}\Omega = 7.0 = 5.0\times10^4 I$;
$I = 1.4\times10^{-4}\,\text{A}$;
$V_{\text{in}} = 1.0 + 1.4\times10^{-4}\times10^4 = 2.4\,\text{V}$; ***[4]***

or

pd across $50\,\text{k}\Omega = \dfrac{50}{60}\,V_{\text{in}} + 6.0$;
$= 7.0\,\text{V}$;
$50V_{\text{in}} + 300 = 420$;
$V_{\text{in}} = 2.4\,\text{V}$;
Award full marks if third marking point is omitted and answer is correct.
Award ***[4]*** *for any other valid method that gives correct answer.*

F3. *moral/ethical issue*:
invasion of privacy;
such as use in public places;

or

private download of illegal material;
such as licensed music films *etc*. / child pornography;

environmental:
manufacture of vast/large/great number of phones (leads to);
depletion of natural sources / production of greenhouse gases / problems with disposal; ***[4]***

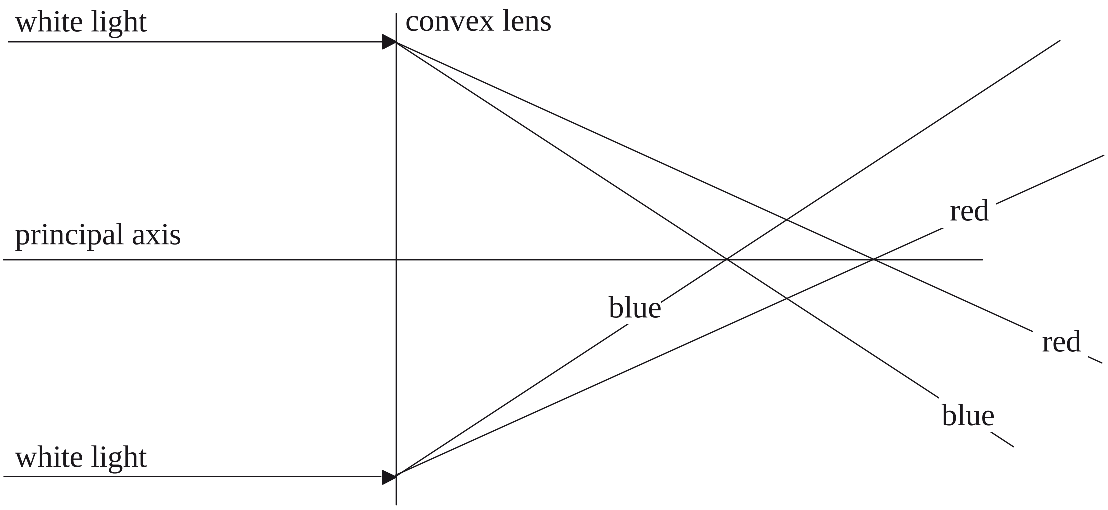
Option G — Electromagnetic waves

G1. (a) the field oscillates too fast for the compass to respond;
the field is too weak; ***[1 max]***

(b) (i) 10^{19} Hz ; *(or above)* ***[1]***

(ii) difficult to modulate the source (which will be a nuclear explosion/ radioactive decay);
difficult to build an appropriate receiver/detector;
negative health effects of exposure to gamma-rays; ***[1 max]***

G2. (a)



paths as shown:
red ray focused;
blue ray focused; ***[2]***
Allow ***[1 max]*** *if colours reversed.*

(b) a different image is formed for each colour of light in the white light;
therefore the resulting image will be multi-coloured;
and out of focus; ***[3]***

(c) use a lens of very long focal length / use a compound lens / use a diffractive optical element / achromatic doublet; ***[1]***

(d) (i) use of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \rightarrow \frac{1}{v}=\frac{1}{8}-\frac{1}{5}$;
$v=-13\text{cm}$; ***[2]***

(ii) ± 2.6; ***[1]***

G3. (a) (i) coherent source; ***[1]***

(ii) $\theta = \frac{\lambda}{d}$ and spacing $= L\theta \rightarrow$ spacing $= L\frac{\lambda}{d}$ ***or*** use of $s = \frac{\lambda D}{d}$;

spacing $= \left(\frac{2.0 \times 700 \times 10^{-9}}{5 \times 10^{-4}} = \right) 2.8\,\text{mm}$; ***[2]***

(iii) sharpen the maxima / finer maxima;
greater contrast between minimum and maximum / brighter maxima; ***[2]***

(b) use of $d\sin\theta = n\lambda$;
with $\theta = 90, n = 4$;
number $= 9$; ***[3]***

G4. (a) (i) zero; ***[1]***

(ii) π ***or*** $\frac{\lambda}{2}$; ***[1]***

(iii) zero; ***[1]***

(b) $2nt = \frac{\lambda}{2}$;
$t = 110\,\text{nm}$; ***[2]***

G5. (a) to produce characteristic spectra the accelerated electrons must have sufficient energy to remove electrons from the inner energy levels (of the molybdenum atoms);
energy required for this is greater than 20 keV; ***[2]***

(b) $\lambda_{\text{min}} = \frac{hc}{eV} = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{1.6 \times 10^{-19} \times 2.5 \times 10^{4}}$;
$= 4.95 \times 10^{-11}\,\text{m}$;
$= 0.050\,\text{nm}$ ***[2]***

(c) $0.20\,\text{nm}$; ***[1]***

Option H — Relativity

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

(b) (i) Aibhe
since proper length is defined as the length of the object measured by the observer at rest with respect to the object / since she is at rest with respect to the object; ***[1]***

(ii) $\gamma = \frac{L_0}{L}$;

$= \left(\frac{1.50}{1.20} = \right) 1.25$;

$1 - \frac{v^2}{c^2} = \frac{1}{1.25^2}$ ***or*** other evidence of algebraic manipulation;

$v = 0.60c$ ***or*** $1.8 \times 10^8\ \mathrm{m\,s^{-1}}$; ***[4]***

(c) $3.0\ \mathrm{s}$; ***[1]***

(d) (because) the speed of light is the same for all <u>inertial</u> observers;
and because of their relative motion Aibhe and Euan will measure different time intervals for the two events;
events which are simultaneous for Aibhe will not be simultaneous for Euan; (*vice versa*) ***[3]***

(e) using the half-life of the muons as measured in the laboratory/their reference frame and the distance between surface and upper atmosphere as measured by Earth observer shows that most muons would have decayed / *OWTTE*;
the half-life measured by the observer on Earth is the dilated time;
relativity predicts that the dilated time will be greater than the proper time so according to Earth observer not all the muons will have decayed / *OWTTE*; ***[3]***
Accept answers in terms of length contraction and proper time.

H2. (a) *particle A*: (the total energy is) the rest mass energy;

particle B: (the total energy is) the rest mass energy plus the kinetic energy; ***[2]***
Do not accept $E^2 = p^2c^2 + m_0{}^2c^4$ *as answer.*

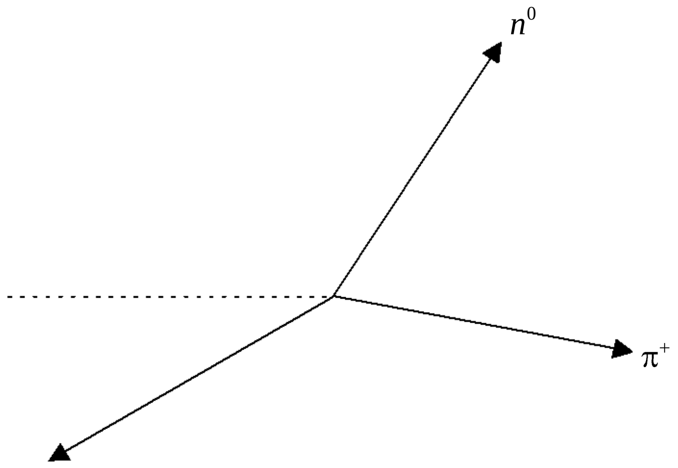
(b) (i) $= \dfrac{0.960 + 0.960}{1 + 0.960^2}$;
$= 0.999\text{c}$; ***[2]***

(ii) $\gamma = 3.57$;
$E = (\gamma m_0 c^2 =) 3.57 \times 938\,\text{MeV}$;
$= 3.35\,\text{GeV}$ ***[2]***

(c) (i) energy before collision $= (3.35 + 3.35 =) 6.70\,\text{GeV}$;
energy of $p + n = (6700 - 502 =) 6.20\,\text{GeV}$; ***[2]***

(ii) $502^2 = p^2c^2 + 140^2$;
$p = 482\,\text{MeV c}^{-1}$; ***[2]***

(d)



as shown; *(accept between 7 o'clock and 9 o'clock)* ***[1]***

H3. (a) a reference system / coordinate system / a means of locating events/objects;
that consists of three space coordinates and a time coordinate; ***[2]***

(b) (the large mass of a) black hole produces (extreme) curvature in spacetime/warps spacetime;
particles follow the shortest path between points in spacetime;
the distance from the singularity to the points where photons/light cannot escape due to the extreme curvature/warping is the Schwarzschild radius; ***[3]***

(c) $\dfrac{2\times7\times10^{-11}\times2\times10^{30}}{9\times10^{16}}$;
$\approx 3\text{km}$ ***[1]***

Option I — Medical physics

I1. (a) lever action (of the ossicles) increases the force;
(this force) acts on small/smaller area (of oval window/cochlear); ***[2]***

(b) (i) the ear responds to differences in intensity/logarithmic response;
each doubling of the intensity leads to the same equal change in loudness / *OWTTE*; ***[2]***

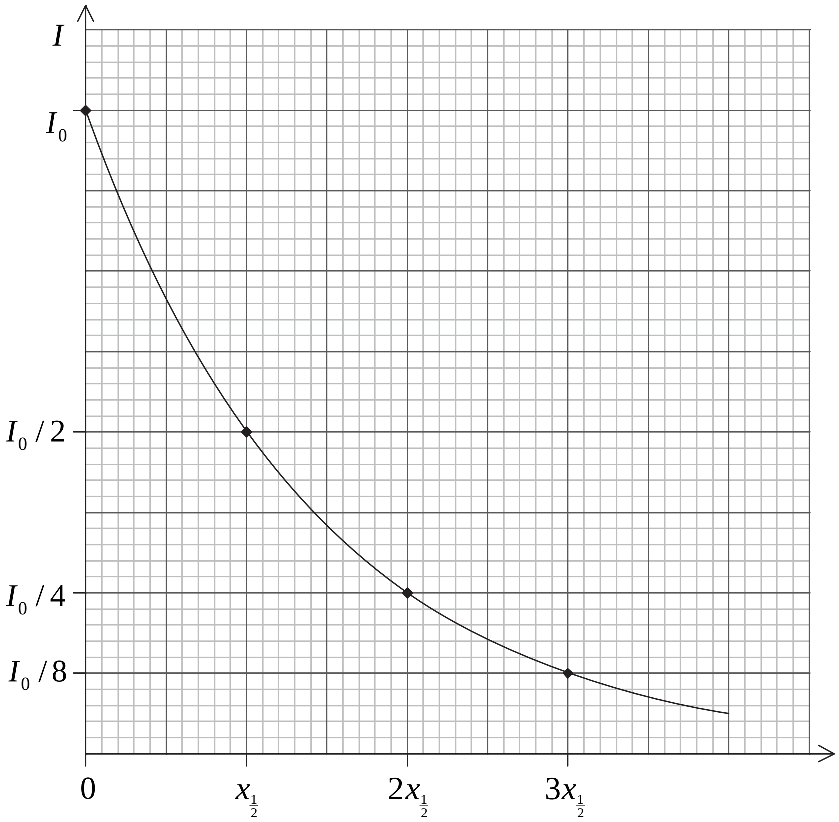
(ii) for $I = 2.0\times10^{-6}\ \mathrm{W\,m^{-2}}$ then $\mathrm{dB} = \left(10\lg\frac{2.0\times10^{-6}}{10^{-12}} = \right)63\,\mathrm{dB}$;

$126 = 10\lg\frac{I}{10^{-12}}$;

$I = 4.0\ \mathrm{W\,m^{-2}}$; ***[3]***

(iii) permanent deafness;
caused by damage to ear drums;
tinnitus;
a permanent ringing in the ears;
selective frequency losses;
due to damage in the inner ear; ***[3 max]***

I2. (a)



first four correct data points; *(judge by eye i.e. data points do not need to be shown)*
smooth curve through data points; ***[2]***

(b) (i) this is the largest ratio of attenuation coefficients and therefore / smallest ratio of half- values thickness;
the distances travelled in the bone and in the tissue will be nearly the same / *OWTTE*;
so much greater reduction in intensity of X-rays in bone than in tissue;
so good contrast between bone and tissue (when image is developed) / *OWTTE*; ***[3 max]***
To award ***[3]*** *answers must have the first and last marking points.*

(ii) $\mu_{\text{tissue}} = \dfrac{0.6}{8.0} = 0.075$;

or

$I_{\text{bone}} = I_0 e^{-0.6\times6.0} = 0.027\, I_0$;
$I_{\text{tissue}} = I_0 e^{-0.075\times9.6} = 0.49\, I_0$;
$\dfrac{0.027}{0.49} \approx 0.055$; *(accept approximate answer)*

(c) (i) visible/red and infrared; ***[1]***

(ii) the amount of light of each wavelength absorbed by hemoglobin depends on whether it is saturated/oxygenated or not / *OWTTE*;
measuring the absorption of the two wavelengths gives a measure of the saturation;
the amount of arterial blood varies with time due to heartbeat so measurement can be isolated from absorption due to bone/tissue/venous blood; ***[3]***

I3. (a) *biological half-life*:
the time it takes for half of the isotope/sample to be removed by natural body functions / *OWTTE*;

physical half-life:
the time for the initial activity (of a sample) to reduce by half; ***[2]***

(b) (i) quickly eliminated by the body; ***[1]***

(ii) has high activity whilst in the body; ***[1]***

(c) 4.0 days is $2 \times T_{\mathrm{B}}$ therefore $\frac{1}{4}$ of the sample left;
physical activity drops by $\frac{1}{2}$;
so total reduction is $\frac{7}{8} = 88\%$; ***[3]***

Accept use of $\frac{1}{T_{\mathrm{E}}} = \frac{1}{T_{\mathrm{P}}} + \frac{1}{T_{\mathrm{B}}}$.
Answer 87% or 88%.

Option J — Particle physics

J1. (a) two or more fermions with identical quantum numbers cannot occupy the same energy level/quantum state;
(whereas) bosons with identical quantum numbers can (occupy the same energy level/quantum state); ***[2]***
Award ***[1 max]*** *for "fermions obey the PEP, bosons do not".*

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

(ii) pion/meson/gluon; ***[1]***

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

$m = \left(\frac{6.6\times10^{-34}}{4\times3.14\times3\times10^{8}\times10^{-15}} = \right)0.18\times10^{-27}\text{ kg}$;

$\frac{0.18\times10^{-27}}{1.68\times10^{-27}}\times940$ ***or*** evidence of other suitable conversion;

$\approx 100\,\text{MeV}$ ***[3]***

(d) (i) *meson*: (positive) – because refers to quark sentence / up quark has charge $+\frac{2}{3}$ and anti-down quark has charge $+\frac{1}{3}$;

anti-muon: (positive) – because muon has negative charge;

[2]

Allow arguments in terms of charge conservation for one ***or*** *other particle.*
To award the mark the reason must be correct.

(ii) W^{+} / positively charged vector boson; ***[1]***

J2. (a) the minimum energy needed to create a particle of rest mass m_0 is m_0c^2;
to conserve for example momentum/charge more than one particle has to be created / *OWTTE*; ***[2]***

(b) (i) the electric field inside the anode is zero / there is no electric field inside the anode; ***[1]***

(ii) *Look for these main points however expressed.*
adjacent anodes are connected to opposite polarity;
as protons leave the source anode 1 is negative and so the protons are accelerated;
whilst inside anode 1 the polarity of all the anodes reverses so that the protons are accelerated on leaving;
anode 1 becomes positive and on leaving anode 2 becomes negative;
protons are now accelerated in the gap between anode 1 and 2 with the process being repeated along the tube; ***[4 max]***

(c) $1890^{2} = 2\ 938\ E + 2\ 938^{2}$;
$E = 966\,\text{MeV}$;
$E_K = (966 - 938 =)\,28\,\text{MeV}$; ***[3]***

(d) *advantage*: ***[1 max]***
colliding beams allow for higher available energy than fixed target;
higher energy more particles may be produced;

disadvantage: ***[1]***
fixed target allows for a higher probability of collision; ***[2 max]***

J3. (a) (i) strangeness is the number of anti-strange quarks minus the number of strange quarks $= 0 - 3 = -3$;
each strange quark has spin $+\frac{1}{2}$; ***[2]***

(ii) quarks obey the Pauli exclusion principle;
without the concept of colour the quark structure of the Ω^- would violate the principle; ***[2]***

(iii) the quarks are confined / the quark colour adds up to zero / the hadron adds up to an observable particle; ***[1]***

(b) (i) the scattering of leptons by nucleons in which the energy and momentum transferred to the nucleon are very large; ***[1]***

(ii) it is possible to measure the total momentum carried by the quarks inside the nucleon;
the total momentum does not equal the momentum of the nucleons and so neutral objects must be present in the nucleon to account for this difference in momentum / *OWTTE*; ***[2]***