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MARKSCHEME

May 2010

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. 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 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 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.

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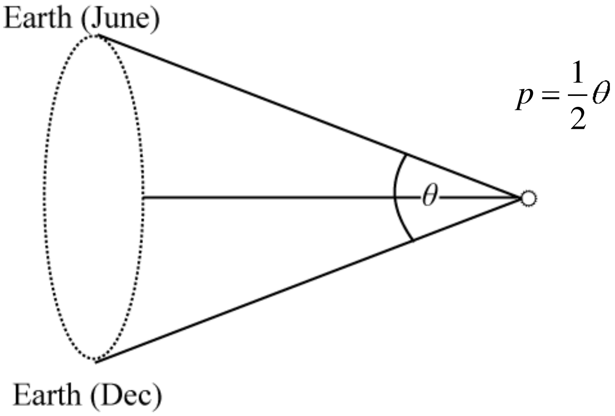
Option E — Astrophysics

E1. (a) (i)



angular position of star measured;
relative to the background of fixed stars;
in two positions six months apart;
p is $\frac{1}{2}$ of the angle of separation / p indicated on diagram; ***[4]***

(ii) $d = \frac{1}{p}\left(= \frac{1}{0.419} = 2.3866 \text{ pc}\right) \approx 2.39 \text{ pc};$
$= 2.3866 \times 3.26 \text{ ly} = 7.78 \text{ ly};$ ***[2]***

(iii) beyond this distance the parallax angle is too small to be measured (accurately) / *OWTTE*; ***[1]***

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

$\frac{L_w}{L_s} = \frac{d_w{}^2 b_w}{d_s{}^2 b_s};$

$d_s = 1 \text{ AU}, d_w = 7.78 \times 6.3 \times 10^4 = 4.9 \times 10^5 \text{ AU};$

$\frac{L_w}{L_s} = [4.9 \times 10^5]^2 \times 3.7 \times 10^{-15} = 8.9 \times 10^{-4};$ ***[4]***

Allow ECF from (a)(ii).

(c) $A = \frac{L}{\sigma T^4}\left(= \frac{3.5 \times 10^{23}}{5.7 \times 10^{-8} \times 2800^4}\right) = 1.0 \times 10^{17} \text{ m}^2;$

$r = \sqrt{\frac{A}{4\pi}}\left(= \sqrt{\frac{1.0 \times 10^{17}}{4\pi}}\right) = 8.9 \times 10^7 \text{ m};$ ***[2]***

(d) temperature too low to be white dwarf;
luminosity too low to be red giant;
radius too small to be a red giant; ***[2 max]***
Answer must be consistent with answer in (c) for third marking point.

E2. (a) density at which universe will expand forever but rate of expansion will approach zero / the density at which the universe will begin to contract after infinite amount of time / the density for which the curvature of the universe is zero / *OWTTE*; ***[1]***

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Reference to "flat" model without definition does not gain mark.

(b) value of density determines whether or not universe will expand forever, or at some point, begin to contract;
at density less than critical density, universe will expand forever;
at density greater than critical density, universe will stop expanding and contract; ***[3]***
If second and third marks gained, first mark is also gained by implication.

(c) dark matter does not radiate/cannot be directly measured/seen; ***[1]***

E3. (a) gas cloud collapses under its own gravity;
gravitational potential energy changes to kinetic energy of particles;
eventually temperature/pressure at centre is so great that fusion occurs; ***[3]***

(b) (initial) mass; ***[1]***

(c) (i) carbon / oxygen / neon; ***[1]***

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

E4. (a) $\frac{\Delta\lambda}{\lambda} \cong \frac{v}{c}$;

$v\left(=\frac{147-122}{122}\times 3.00\times 10^{5}=61475\,\text{kms}^{-1}\right)\approx 61500\,\text{kms}^{-1}$;

$d=\frac{v}{H_0}\left(=\frac{61475}{75}=819.67\,\text{Mpc}\right)\approx 820\,\text{Mpc}$; ***[3]***

(b) difficulty in determining galactic distances; ***[1]***

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Option F— Communications

F1. (a) (i) (amplitude / frequency of) wave is modified/changed; ***[1]***

(ii) to carry information; ***[1]***

(b) amplitude constant (at 8.0 V);
frequency changes by ± 18 kHz;
from 482 kHz to 518 kHz and back to 482 kHz;
2500 times per second; ***[4]***

F2. (a) (i) area (under line) represents energy;
smaller area so energy loss; ***[2]***

(ii) (output) curve is not smooth;
showing random additional power/energy; ***[2]***
*Accept for **[1]** height in output power curve is smaller.*

(b) (i) material dispersion (dependence of wave speed on wavelength);
modal dispersion (dependence of wave speed on path taken); ***[2]***
*Award **[1]** if only dispersion is mentioned.*

(ii) pulses would overlap; ***[1]***

F3. (a) (i) satellite that orbits with a period of 24 hours / same period of rotation as Earth;
hence remaining above the same position on the Earth's surface/above equator; ***[2]***

(ii) do not need to be tracked;
can be used for continuous communication; ***[2]***

(b) polar-orbiting satellite closer to Earth's surface / lower orbit;
so less expensive to put into orbit;
so lower power signals required;
so time delay between transmission and reception less; ***not** faster speed of transmission*
covers whole of Earth's surface during several orbits;
so communication over whole of surface; ***[3 max]***

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F4. cellular exchange monitors signal strength;
from base stations;
using a computer;
(and) switches between base stations;
to maintain maximum signal strength; ***[5]***

F5. (a) gain $= 1 + \frac{R_F}{R_{\text{IN}}}$;

$= 1 + \frac{10}{2} = 6$; ***[2]***

(b) (i) 5.4 V;
negative; ***[2]***

(ii) 9.0 V; ***[1]***

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Option G — Electromagnetic waves

G1. (a) (i) between lenses and between eye lens and F; *[1]*

(ii) further from eye lens than image X and same distance from eye lens for both points; (*judge by eye*) *[1]*

(iii) final image near object and not between lenses; *[1]*
Accept markings of positions even when shown off the principal axis except for the focal points.

(b) central cross shown straight;
sides curved (outwards or inwards); *[2]*

(c) lens has different refractive indices for different wavelengths/colours;
so each wavelength/colour has a different focal length; *[2]*

G2. (a) (i) λ_{red} : allow 620 nm → 780 nm; *[1]*

(ii) λ_{blue} : allow 320 nm → 480 nm; *[1]*

(b) light travels (towards observer) further through atmosphere at sunset (compared to during the day);
(short wavelength) blue light scatters the most;
and so with blue removed (from the light reaching the observer) the Sun looks red; *[3]*
Award second and third marks for reversal of wavelengths in (a).

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G3. (a) (i) (light from the slits has) constant phase difference; ***[1]***

(ii) when two (or more) waves meet;
resultant displacement;
is sum of individual displacements; ***[3]***

or

when the path difference;
is an integral/half-integral multiple of the wavelength;
constructive/destructive interferences take place;
Allow amplitude for 3rd mark.

(b) $x = \frac{\lambda d}{a} \quad = \frac{640 \times 10^{-9} \times 2.4}{0.85 \times 10^{-3}}$;
$= 1.8 \times 10^{-3}\,\text{m}$; ***[2]***

(c) bright fringes are less bright;
dark fringes are brighter; ***[2]***

G4. (a) $eV = \frac{hc}{\lambda}$;
$\left(1.6 \times 10^{-19} \times 45 \times 10^{3} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{\lambda}\right)$
$\lambda = 2.8 \times 10^{-11}\,\text{m}$;
range is $2.8 \times 10^{-11}\,\text{m}$ and longer; ***[3]***

(b) some electrons have enough energy to remove an electron from the inner shell of an atom;
an electron falls from an outer energy level to the inner energy level;
emitting an X-ray photon of characteristic wavelength; ***[3]***

G5. (a) correct reflections at both surfaces;
correct refraction at top surface; ***[2]***

(b) for one angle of viewing, one colour interferes destructively/another interferes constructively;
white light minus that colour is seen / colour seen is determined by colour that interferes constructively;
at different viewing angle, different colour interferes destructively/constructively; ***[2 max]***

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Option H — Relativity

H1. (a) a co-ordinate system (in which measurements of distance and time can be made); which is not accelerating/in which Newton's laws are valid; ***[2]***

(b) (i) $\text{Time} = \frac{\text{Distance}}{\text{Speed}}\left(= \frac{8.8}{0.80}\right) = 11$ years; ***[1]***

(ii) Ann;
according to Ann, the two events of leaving Earth and arriving at Sirius occur at the same point in space; ***[2]***
*Award **[0]** for bald correct answer or incorrect explanation.*

(iii) $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}\left(= \frac{1}{\sqrt{1-\frac{0.8^2 c^2}{c^2}}} = 1.667\right) \approx 1.7$;

$\text{Time for Ann}\left(= \frac{11}{1.667}\right) = 6.6$ years; ***[2]***

(iv) let t be the time signal takes to reach Earth according to Ann. In this time, Ann would move further away from the Earth by the distance vt, where $v = 0.80\text{c}$;
starship and Earth originally separated by 5.28 light-years, according to Ann;
so $5.28 = ct - vt \Rightarrow t\left(= \frac{5.28 \text{ light years}}{\text{c} - 0.8\text{c}}\right) = 26$ years; ***[3]***

(c) (i) (the paradox is that) Ann will appear to age more slowly to Sue but Sue will appear to age more slowly to Ann / *OWTTE*; ***[1]***

(ii) Ann is in an accelerating reference frame;
so situation is not symmetrical / Ann changes from one inertial frame into another; ***[2]***

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H2. (a) mass measured in reference frame in which object is at rest / *OWTTE*; ***[1]***

(b) as speed approaches c, mass approaches infinity / the energy required to accelerate particle increases its mass-energy;
at c, energy required would be infinite / mass would be infinite which is impossible / *OWTTE*; ***[2]***

(c) $u_x' = \dfrac{u_x - v}{1 - \dfrac{u_x v}{c^2}}$;

$= \dfrac{0.7\text{c} - (-0.7\text{c})}{1 - \dfrac{0.7\text{c} \times (-0.7\text{c})}{c^2}}$;

$= 0.94\text{c}$; ***[3]***

or

$= \dfrac{-0.7\text{c} - 0.7\text{c}}{1 - \dfrac{(-0.7\text{c}) \times 0.7\text{c}}{c^2}}$;

$= -0.94\text{c}$;

(d) $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}} = \left(\dfrac{1}{\sqrt{1 - \dfrac{(0.7c)^2}{c^2}}}\right) = 1.4$;

$E_K = [\gamma - 1] m_o c^2 = [1.4 - 1] \times 938 = 380\,\text{MeV}$;

hence $V = 380\,\text{MV}$; ***[3]***

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H3. (a) distance from singularity at which light can no longer escape / *OWTTE*; ***[1]***

(b) $R_S = \left(\frac{2GM}{c^2} = \right)\frac{2\times 6.7\times 10^{-11}\times 2.0\times 10^{31}}{[3.0\times 10^8]^2}$;

$= 3.0\times 10^4$ m ; ***[2]***

(c) (i) photons move upwards through gravitational field and so lose energy;
since $E = hf$, frequency decreases;

or

if space station were accelerating away from starship, signal would undergo Doppler shift towards lower frequency;
by equivalence principle, passing through gravitational field has same effect as acceleration; ***[2]***

or

the inverse of frequency is period that can be used as a clock;
since time slows down near a massive body, the period and so frequency must change;

(ii) $\frac{\Delta t}{\Delta t_0} = \frac{1}{\sqrt{1-\frac{R_s}{r}}} = 10$;

$\frac{1}{100} = 1 - \frac{R_s}{r} \Rightarrow \frac{R_s}{r} = 0.99$;

$r = 1.01R_s$ and so distance $= 0.01R_s$; ***[3]***

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Option I — Medical physics

I1. (a) (i) $\text{intensity} = \frac{\text{power}}{\text{area}}$;

$$= \frac{0.19\times10^{-6}}{54\times10^{-6}}$$

$$= 3.5 \text{ mW m}^{-2};$$ *[2]*

(ii) $IL = 10\lg\left[\frac{I}{1.0\times10^{-12}}\right]$;

$$= 10\lg\left[\frac{3.5\times10^{-3}}{1.0\times10^{-12}}\right]$$

$$= 95 \text{ dB};$$ *[2]*

(b) short-term use → tinnitus;
long-term use → deafness / loss of frequency range of hearing; *[2]*

I2. (a) product of density of medium and speed <u>of wave in medium</u>; *[1]*

(b) (i) $I_R = \left(\frac{1.63\times10^6 - 430}{1.63\times10^6 + 430}\right)^2$;

$I_R \approx 1$; *[2]*

(ii) the difference between the impedances of tissue and air is very large / $I_R \approx 1$;
(most) ultrasound is not transmitted into the body;
ultrasound would not be transmitted out of the body / on leaving body attenuation will occur again; *[3]*

(iii) use a gel between the transducer and the skin;
gel has about same acoustic impedance as (transducer and) skin; *[2]*

I3. (large) uniform magnetic field applied to patient;
pulse of radio-frequency waves;
either at Lamor frequency of H-nuclei
or cause H-nuclei to resonate;
H-nuclei de-excite giving off radio-frequency waves;
these waves detected and processed;
to give positions of H-nuclei;
non-uniform B-field enables positions to be defined; ***[6 max]***

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I4. (a) (i) total charge of one sign produced (by ionisation) per unit mass of air; *[1]*

(ii) energy absorbed by tissue; *[1]*

(iii) absorbed dose taking into consideration type of radiation/density of ionisation; *[1]*

(b) number of ion pairs produced in 1 kg of air $= \dfrac{2.5\times10^{-3}}{1.6\times10^{-19}}$
$= 1.56\times10^{16}$;

energy given to 1 kg $= 1.56\times10^{16}\times1.6\times10^{-19}\times34$;
$= 8.5\times10^{-2}$ J;

energy given to 1 g of air $= 8.5\times10^{-5}$ J; *[4]*

(c) (i) *e.g.* risk of developing cancer; *[1]*
Do not allow any short-term effect.

(ii) risk much less than risk associated with untreated situation;
risk accepted because there is improvement in quality of life; *[2]*

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Option J — Particle physics

J1. (a) (i) $W^+ / W^- / Z^0$ (boson); *[1]*

Do not insist on superscripts.

(ii) photon / γ ; *[1]*

(b) range of interaction is inversely proportional to mass of exchange particle / range of interaction is given by $\frac{h}{4\pi mc}$ with symbols defined;

bosons have mass, photons do not, hence range of electromagnetic interaction is infinite, range of weak interaction is finite / *OWTTE*; *[2]*

(c) electromagnetic interaction between two electrons / electron-electron scattering / collision of electron with electron; *[1]*

(d) a particle that appears as an intermediate particle in a Feynman diagram / a particle that is not (directly) observed / (temporarily) violates energy/momentum conservation; *[1]*

(e) $\Delta E \Delta t \geq \frac{h}{4\pi}$ with symbols defined;

virtual photon can exist, temporarily breaching energy conservation, for a time that depends on its energy; *[2]*

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

$\left(= \frac{6.6 \times 10^{-34}}{4\pi \times 1.6 \times 10^{-16}} \right) = 3.3 \times 10^{-19}$ J; *[2]*

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J2. (a) chamber contains a superheated liquid (obtained by reducing pressure);
particles passing through cause ionisation;
this causes bubbles to form on the ions; ***[3]***

(b) faster data collection;
data can be digitised (and hence analysed by computer);
no dead time between photographs; ***[2 max]***

(c) particles lose energy and hence speed as they pass through the chamber;
therefore radius of orbit decreases;
since $v = \frac{qBr}{m}$ ***or*** r proportional to v; ***[3]***

J3. (a) *mesons:* quark and anti-quark;
baryons: three quarks/anti-quarks; ***[2]***

(b) *mesons:* colour cancels out anti-colour;
baryons: red green blue combine to make colourless particle; ***[2]***

(c) (i) zero; ***[1]***

(ii) baryons have baryon number +1, mesons have baryon number 0;
by conservation of baryon number, $0+1=1+\text{X}$, so $\text{X}=0$, so X is a meson; ***[2]***

J4. (a) minimum energy required is rest energy of positron and electron $=2\times0.511\text{ MeV}=1.022\text{ MeV}$;
corresponding to a temperature of
$T=\frac{2E}{3k}$;
$\left(\frac{2\times1.022\times1.6\times10^{-13}}{3\times1.38\times10^{-23}}\right)=7.9\times10^{9}\approx10^{10}\text{ K}$; ***[3]***

(b) temperature has cooled to a point at which spontaneous pair production has become impossible;
pair annihilation is still possible; ***[2]***

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