International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

MARKSCHEME

May 2014

PHYSICS

Standard Level

Paper 3

Subject Details: Physics SL Paper 3 Markscheme

Mark Allocation

Candidates are required to answer questions from **TWO** of the Options **[2 × 20 marks]**.
Maximum total = **[40 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 A — Sight and wave phenomena

1. (a) green;   *[1]*

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

        (ii) cone cells used in bright light;
              cone cells mostly at fovea/principal axis/centre of retina;   *[2]*

2. (a) change in the observed/perceived frequency;
        when there is relative motion between the source and the observer / when either
        the source or observer is moving;   *[2]*

    (b) (i) $f = 850 \left[\dfrac{330}{330 + 6.5} \right]$;

              $f = 830 \,(\text{Hz})$;   *[2]*

              Award [1 max] for correct answer if moving observer equation is used with
              6.5 in the numerator or if the approximate formula is used.

        (ii) frequency increases;
              (from $830\,(\text{Hz})$) to $870\,(\text{Hz})$;   *[2]*

3. (a) for the images (of two sources) just to be resolved/distinguished/seen as separate;
        central maximum of one diffraction pattern must coincide with first minimum of
        second / *OWTTE*;   *[2]*
        Accept a suitably drawn diagram for the second marking point.

    (b) (i) $\theta = \left(\dfrac{1.22 \times 550 \times 10^{-9}}{2.0 \times 10^{-3}} = \right) 3.4 \times 10^{-4}\,(\text{rad})$ ***or*** $0.019°$;   *[1]*

        (ii) $d = 11 \times 10^{3} \times 3.4 \times 10^{-4}$;
              $= 3.7\,(\text{m})$;   *[2]*
              Award [2] for a bald correct answer.

    (c) pupil has smaller diameter;
        (wavelength unchanged so) lower resolution / larger minimum angle of
        separation;
        distance (from towers) decreases/less than 11 km;   *[3]*

    (d) reflected light is (partially) polarized parallel to sea surface/horizontally polarized;
        sunglasses have a transmission axis at $90°$ to reflected light/vertical transmission
        axis;   *[2]*

Option B — Quantum physics and nuclear physics

4.   (a)   all particles have an associated wavelength / *OWTTE*;

wavelength given by $\lambda = \dfrac{h}{p}$, where h is Planck's constant and p is momentum;   *[2]*

(b)   (i) $E_{\mathrm{K}} \left(= 3.2 \times 10^{-19} \times 25 \times 10^{3} \right) = 8.0 \times 10^{-15}$ (J) *or* 50 (keV);   *[1]*

(ii)   <u>use</u> of $E_{\mathrm{K}} = \dfrac{p^{2}}{2m}$ and $p = \dfrac{h}{\lambda}$ *or*   <u>use</u> of $E_{K} = \frac{1}{2}mv^{2}$ and $p = mv = \dfrac{h}{\lambda}$;

$p = 1.0 \times 10^{-20}$ (Ns);

$\lambda = \left(\dfrac{h}{p} = \right) 6.6 \times 10^{-14}$ (m) *or* 6.5×10^{-14} (m);   *[3]*

Award [3] for a bald correct answer.

5.   (a)   each line represents a single frequency/wavelength;
which corresponds to a specific photon energy / $E = hf$;
energy of photon determined by energy change of electrons;
electrons transition between energy levels (so discrete energy levels);   *[3 max]*
Award [3 max] for reverse argument that discrete energy levels produce line spectra.

(b)   (i) $\Delta E = \left[13.6 - 3.40 \right] \times 1.60 \times 10^{-19} \left(= 1.63 \times 10^{-18}\ \mathrm{J} \right)$;

$E = \dfrac{hc}{\lambda}$; *(accept implicit use of this equation)*

$\lambda = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{1.63 \times 10^{-18}} = 1.22 \times 10^{-7}$ (m);   *[3]*

Award [3] for a correct bald answer.

(ii)   photon absorbed when its energy is equal to the difference between two
energy levels;
so absorption not possible;   *[2]*

6.   (a)   probability of decay (of a nucleus) per unit time;   *[1]*

Accept $\dfrac{A}{N}$ with symbols defined.

(b) $N = N_0\, e^{-\lambda t}$ and $N = \dfrac{N_0}{2}$ when $t = T_{\frac{1}{2}}$ *or* $\dfrac{N_0}{2} = N_0\, e^{-\lambda T_{\frac{1}{2}}}$;

$\dfrac{1}{2} = e^{-\lambda T_{\frac{1}{2}}}$ *or* $2 = e^{\lambda T_{\frac{1}{2}}}$;

$\left(\text{so } \ln 2 = \lambda T_{\frac{1}{2}}\right)$ *[2]*

Answer given, award marks for correct working only.

(c) $\lambda = \dfrac{\ln 2}{28}$ *or* $0.025 \left[y^{-1} \right]$;

$0.35 = e^{-0.025t}$;

$t = 42$ (years);   *[3]*

Award [3] for a bald correct answer.

Award [2 max] for an answer of 17 years (using 0.65 instead of 0.35).

or

$0.35 = \left[\dfrac{1}{2} \right]^x$ where $x = \dfrac{t}{T_{\frac{1}{2}}}$;

$\dfrac{t}{T_{\frac{1}{2}}} = 1.5$;

$t = 42$ (years);

Award [3] for a bald correct answer.

Award [2 max] for an answer of 17 years (using 0.65 instead of 0.35).

Option C — Digital technology

7. (a) (i) 10110; *[1]*

(ii) the digital information is imprinted as a series of lands and pits / *OWTTE*;
which form a (spiral) track on the surface of the CD;
with the edge of lands/pits being assigned binary 1 and the rest binary 0; *[2 max]*
Allow the switching of 0 and 1.
Allow any consistent description of lands and pits.

(iii) a laser directed at the surface of the CD is reflected;
destructive interference takes place from the edge of land-pit leading to binary 1;
with other reflections leading to binary 0; *[2 max]*
Allow the reversal of 0 and 1.

(b) (i) intensity / power per square meter (of light); *[1]*

(ii) number of incident photons is $\dfrac{4.5 \times 10^{-16}}{6.63 \times 10^{-34} \times 6.2 \times 10^{14}} = 1.09 \times 10^{3}$;

number of emitted electrons is $0.84 \times 1.09 \times 10^{3} = 9.16 \times 10^{2}$;

charge accumulated is $9.16 \times 10^{2} \times 1.6 \times 10^{-19} = 1.47 \times 10^{-16}$ (C);

so potential difference is $V = \left(\dfrac{Q}{C} = \dfrac{1.47 \times 10^{-16}}{25 \times 10^{-12}} = \right) 5.9 \, (\mu V)$; *[4]*

Award [4] for a bald correct answer.

8.   (a)   (i)   infinite (open loop) gain / infinite input resistance/impedance / zero output /
                     infinite bandwidth / infinite slew rate;   *[1]*

        (ii) $G = \left(-\dfrac{R_F}{R} = -\dfrac{75}{15} = \right) -5.0$; *(negative sign required)*   *[1]*

        (iii) $V_{in} = \dfrac{6.0}{-5.0} = -1.2\,(V)$; *(watch for ECF from (a)(ii))*   *[1]*

   (b)
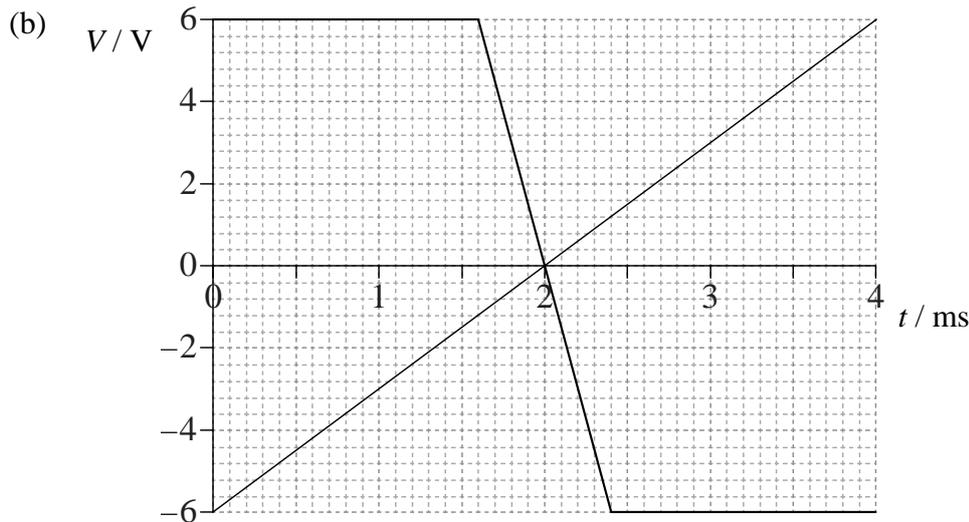
   slew <u>gradient</u> negative; *(allow ECF from (a)(iii))*
   saturation voltage $+6\,V$ <u>and</u> $-6\,V$; *(both needed)*
   switches at $\pm1.2\,V$ (reaches saturation at $1.6\,ms$ <u>and</u> | *(both needed)*
   $2.4\,ms$); | *(allow ECF from (a)(iii))*   *[3]*
   In third marking point allow + or – one grid square.
   Allow second and third marking point independently from first marking point.

9.   mobile phone sends signal to base stations;
   cellular exchange selects base station with strongest signal;
   cellular exchange allocates frequency;
   cellular exchange allocates different base station as passenger changes cell;
   PSTN forwards call to PSTN of other country;   *[4 max]*

Option D — Relativity and particle physics

10. (a)   because the events occur at the same place/point in space for this observer;   *[1]*
      Do not allow "events within the same reference frame".

   (b)   (i) $t = \left(\dfrac{12}{0.60c} = \right) 20\,(\text{yr})$;   *[1]*

      (ii) $\gamma = \left(\dfrac{1}{\sqrt{1-0.60^2}} = \right) 1.25$;   *(allow implicit value)*

         $t_{\text{rocket}} = \left(\dfrac{20\,\text{yr}}{\gamma} = \right) 16\,(\text{yr})$;   *(allow ECF)*   *[2]*

         Award [2] for a bald correct answer.

   (c)   (i) $L = \left(\dfrac{12\,\text{ly}}{\gamma} = \right) 9.6\,(\text{ly})$;   *(allow ECF from (b)(ii))*   *[1]*

      (ii) $v = \left(\dfrac{9.6\,\text{ly}}{16\,\text{y}} = \right) 0.60c$;   *(allow ECF from (b)(ii) and (c)(i))*   *[1]*

      (iii)   (by principle of relativity this should be the) same as the speed of the
         spaceship relative to Earth;   *[1]*

   (d)   both signals travel at the same speed c;
      Judy must agree that the signals arrive at S simultaneously / *OWTTE*;
      for Judy, observer S moves away from the signal traveling from P/towards the
      signal traveling from Earth;
      for Judy the signal from P has further to travel to reach S – so was emitted first;   *[3 max]*
      *Do not accept explanations based on Judy approaching P or seeing/receiving the
      signal from P first as this is irrelevant.*
      Award [0] for a bald correct answer.

11. (a) (i) kaons are bosons/mesons and have integral spin;
the Pauli exclusion principle only applies to fermions not bosons/applies to
half-integral spin particles; *[2]*

(ii) free quarks cannot be produced (quark/colour confinement);
as energy is supplied the separation of the quarks increases;
eventually a new meson/baryon will be produced / formation of quark – anti
quark pair with colour – anti colour; *[3]*

(b) (i) the decay does not conserve strangeness;
and only the weak interaction violates strangeness conservation; *[2]*

or

a neutrino is produced in this decay;
neutrinos interact only via the weak interaction;

(ii) $R = \left(\dfrac{h}{4\pi mc} = \right) \dfrac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{4\pi \times \left[80 \times 10^{9} \times 1.6 \times 10^{-19} \right]}$;

$R = 1.2 \times 10^{-18}$ (m) ; *[2]*
No ECF if wrong value for m is used.

(c) does not conserve baryon/quark/lepton number; *[1]*

Option E — Astrophysics

12. (a) (i) stars, and not planets, have cores undergoing fusion;
stars have much greater mass/luminosity/absolute magnitude/temperature than planets;
planets reflect starlight rather than emit;
planets in our solar system can show retrograde motion, stars cannot;   *[1 max]*
Allow other sensible answers.

(ii) stars in a stellar cluster are close to each other/kept together by gravitation, the stars in a constellation are not;   *[1]*

(b) (i) the lines in the (absorption) spectrum of the star (correspond to hydrogen wavelengths);   *[1]*

(ii) the gravitational force that tends to collapse the star is balanced by a force due to radiation pressure;   *[1]*

(c) peak wavelength is at 400 (nm); *(accept answers in the range of 380 to 420 (nm))*
$T = \left(\dfrac{2.9 \times 10^{-3}}{400 \times 10^{-9}} = \right) 7250$ (K); *(accept answers in the range of 6900 to 7600 (K))*   *[2]*
Award [2] for a bald correct answer.

13. (a) (i) (apparent) brightness;   *[1]*

(ii) the star expands and contracts / the star's radius varies / the star's surface temperature varies / the star's surface area varies;   *[1]*

(b) period is 6.6 days; *(allow ± 0.4 days)*
$M = (-2.81 \lg_{10} 6.6 - 1.43 =) -3.73 \pm 0.07$;
average apparent magnitude m is 15.55 ± 0.05;
use of $m - M = 5 \lg_{10} \dfrac{d}{10}$ to give $d = 10 \times 10^{\frac{15.55 - (-3.73)}{5}}$;
$= 72$ (kpc); *(accept answers in the range of 68 to 75 (kpc))*   *[5]*
Allow ECF [4 max] if value other than 6.6 days is used, or value other than 15.55 is used for m, or value other than –3.73 for M.

(c) $L = 4\pi d^2 b$; *(marks are always for the formula re-arrangement or use)*
$L = 4\pi \left(72 \times 10^3 \times 3.26 \times 9.46 \times 10^{15} \right)^2 \times 1.5 \times 10^{-14}$;
$L = 9.3 \times 10^{29}$ (W); *(accept answers in the range of 8.5×10^{29} to 10×10^{29} (W))*   *[3]*
Award [3] for a bald correct answer.
Watch for ECF from (b).
If d is left in pc, do not allow ECF for third marking point.

14. (a)   <u>electromagnetic radiation</u> in the microwave region;
black body radiation (at a temperature of about 3 K);
(almost) isotropic/uniform radiation;
radiation that fills the universe/exists everywhere/has no obvious point of origin;   *[2 max]*

    (b)   CMB radiation was a prediction of the Big Bang model;
CMB "temperature" is consistent with a universe that has cooled from an initial hot state;
CMB wavelength is consistent with a universe that has expanded from an initial hot, dense state;
CMB isotropy/uniformity is consistent with its origin in the very early universe;   *[2 max]*

Option F — Communications

15. (a) (i) the modification of a carrier's frequency by an amount that depends on the signal wave's displacement;
while leaving the amplitude constant; *[2]*

(ii) *V* / V
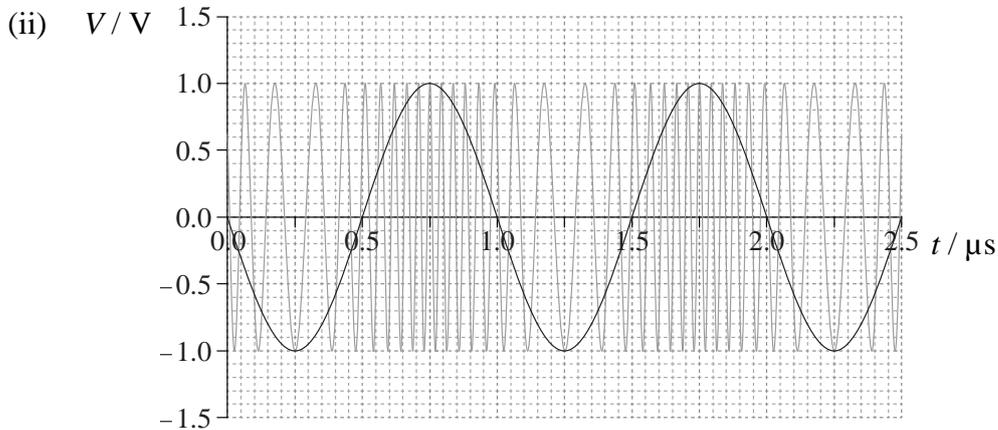
correct amplitude (1 V);
correct period shown □ 1.0 µs ; *[2]*
Allow inverse of waveform shown.

(b) (i) there are 15 full waves in 1.0 µs so the frequency is 15 (MHz); *[1]*
Allow 14 to 16 (MHz).

(ii) period of signal wave is 1.0 (µs);
and so frequency is 1.0 (MHz); *(allow ECF from (a)(ii))* *[2]*
Warning: it easy to mistakenly award only [1] for a correct response.

(c) *advantage*: *[1 max]*
better signal to noise ratio / information transmitted with less power / greater bandwidth;
Do not accept vague terms such as "better quality".
Allow other valid responses.

disadvantage: *[1 max]*
complex circuits / smaller range; *[2]*
Do not accept "expensive".
Allow other valid responses.

16. (a)   there are 8 samples during 1.0 ms/the period of sampling is $\frac{1.0}{8} = 0.125$ (ms);

so the sampling frequency is $\left(\frac{10^3}{0.125} = \right) 8.0$ (kHz);   *[2]*

Allow ECF for incorrect value used from first marking point.

(b)   (the quantization error is 1.0 V so) the number of levels is $\frac{12}{1} = 12$;

12 is 1100 so we need 4 bits; *(allow ECF from first marking point)*   *[2]*
Accept bald correct statement.

(c)   the voltage is 7 V and so 0111; *(all four bits are required)*   *[1]*
Try to allow ECF if quantization error other than 1.0 V was assumed in (b).

17. (a)   the loss of power in the transmission of a signal / *OWTTE*;   *[1]*

(b)   (i)   power when signal to noise ratio is 35 dB is

$\left(10\lg \frac{P_{\text{signal}}}{52 \times 10^{-12}} = 35 \Rightarrow P_{\text{signal}} = 52 \times 10^{-12} \times 10^{3.5} = \right) 1.6 \times 10^{-7}$ (W);

attenuation is $\left(10\lg \frac{88 \times 10^{-3}}{1.6 \times 10^{-7}} = \right) 57.4$ (dB);

distance $= \left(\frac{57.4}{2.6} = \right) 22$ (km);   *[3]*

Award [3] for a bald correct answer.

Accept alternative approaches eg:

$10\lg \left(\frac{P_s}{P_n}\right) = 92.3 \text{(dB)}$;

$92.3 - 35 = 57 \text{(dB)}$;

$\frac{57}{2.6} = 22 \text{(km)}$;

Award [3] for a bald correct answer.

(ii)   speed of light in core of fibre is $\left(\frac{5.6 \times 10^6}{28 \times 10^{-3}} = \right) 2.0 \times 10^8 \text{(m s}^{-1})$;

$n = \left(\frac{3.0 \times 10^8}{2.0 \times 10^8} = \right) 1.5$;   *[2]*

Option G — Electromagnetic waves

18. (a) (i) the point on the principal axis;
through which rays parallel to the principal axis pass after going through the lens / from which rays are parallel to the principal axis after passing through the lens; *[2]*
Allow marking points on a labelled diagram.

(ii)

convex lens
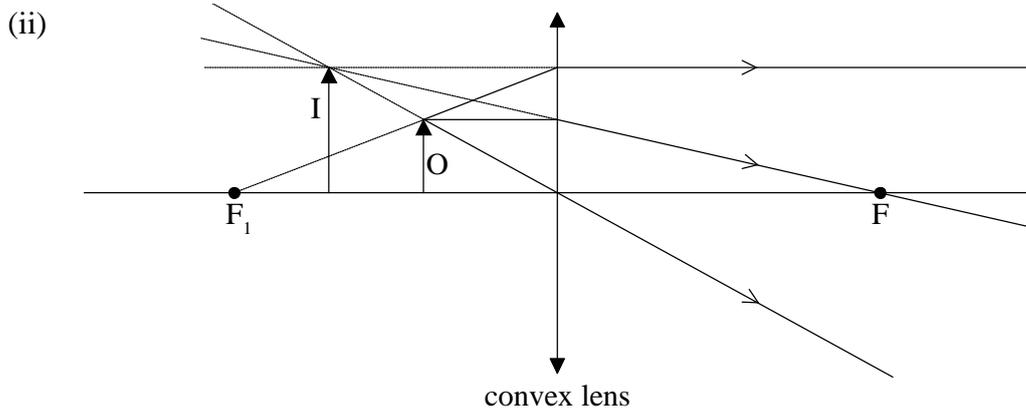
any correct ray of the three shown in the diagram;
second ray correct;
image shown correctly, between O and F_1; *[3]*
Accept rays without arrows and solid construction lines back to the image.

(b) (i) closest point on which the eye can focus (comfortably); *(allow closest distance)* *[1]*

(ii) gives maximum angular magnification (without straining the eye); *[1]*

(c) (i) separation $= 96$ (cm); *[1]*

(ii) $M = \left(\dfrac{f_o}{f_e} = \right) \dfrac{90}{6.0}$;
$M = 15$; *[2]*

19. (a) (i) constant/zero phase difference (between the light waves); *[1]*

(ii) single/same wavelength/frequency; *(allow "narrow band" OWTTE)* *[1]*
Do not allow "single colour".

(b) $180°$ / π rad; *[1]*
Do not accept $\dfrac{\lambda}{2}$.

(c) (i) <u>use</u> of $\lambda = \dfrac{sd}{D}$;

$s = \underline{2} \times 1.8$ (mm); *(award this mark for any evidence for the factor of 2)*

$\lambda = \dfrac{2 \times 1.8 \times 10^{-3} \times 0.30 \times 10^{-3}}{1.5}$ / *OWTTE*;

$(= 7.2 \times 10^{-7} \text{ m})$ *[3]*
Exact answer is given, award marks for correct working.

(ii) $3.6 \times 10^{-7} \text{ m}$ ***or*** 360 nm; *[1]*
Allow ECF from (c)(i).

(d) <u>use</u> of $d = \dfrac{n\lambda}{\sin \theta}$;

$d = \dfrac{3 \times 720 \times 10^{-9}}{\sin 39°} = 3.4 \times 10^{-6} \text{ (m)}$;

$N = \left(\dfrac{1}{3.4 \times 10^{-6}} = \right) 2.9 \times 10^{5}$; *[3]*

Award [3] for a bald correct answer.
ECF examples:
Award [2 max] if n=2 is used (gives 4.4×10^{5}).
Award [2 max] if 78° is used (gives 4.5×10^{5}).
Award [2 max] if 13° and n=1 used (gives 3.1×10^{5}).