SECTION A

A1. (a) a straight line / linear graph cannot be drawn that lies within all the error bars; *[1]*

(b) smooth curve;
that does not go outside error bars; *[2]*

(c) recognize that D_λ is the gradient of the graph;
suitable triangle $\Delta\lambda \geq 100$ nm;
to give magnitude $1.15 - 1.40 \times 10^{-5}\,\text{nm}^{-1}$ / $10^{4}\,\text{m}^{-1}$;
negative sign; *[4]*

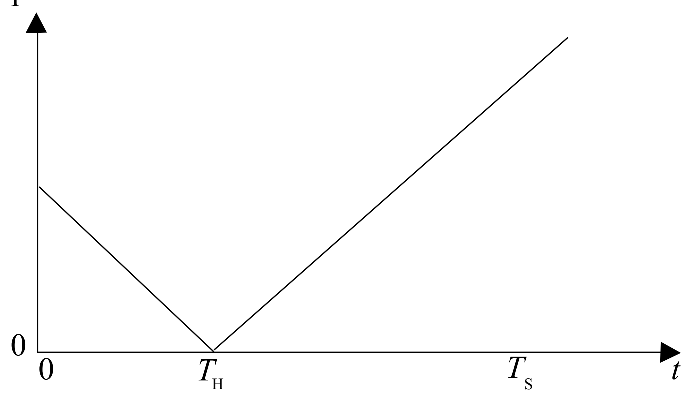
(d) lg$n$ against lgλ;
$\lg n = \lg k + p \lg \lambda$;
slope/gradient $= p$; *[3]*

(e) (i) recognize that A is the intercept on the n axis;
line shown extrapolated;
$A = 1.6020(\pm 0.0001)$; *[3]*
Award full marks for correct answer with omission of first marking point award ***[2 max]*** *if they find the gradient (B) and then use a data point to calculate A.*

(ii) it is the value of n / refractive index for an infinite wavelength / $\lambda =$ infinity / minimum value of n; *[1]*

A2. (a) initial KE of stone + loss in PE = gain in KE / or equivalent statement;
$\frac{14^2}{2} + 9.8 \times 28 = \frac{v^2}{2}$;
to give $v = 27\ \text{m s}^{-1}$; *[3]*
Must be some indication that an energy method used for max credit otherwise ***[max 1]***.

(b)



two lines going in the correct direction as shown;
speed greater at sea than initial speed;
(magnitude of) slopes the same; *(judge by eye)*
zero at T_H; ***[4]***
*Award **[2 max]** if lines do not go to zero.*
*Award **[1 max]** if initial speed zero and then going to zero at* T_H.

A3. (a) (i) an atom or nucleus that is characterized by the constituents of its nucleus / a particular type of atom or nucleus / *OWTTE*;
(in particular) by its proton (atomic) number and its nucleon number / number of protons and number of neutrons; ***[2]***

(ii) nuclides that have the same proton number but different nucleon number / same number of protons different number of neutrons; ***[1]***

(b) (i) $^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + \beta^- + \bar{\nu}$
β^- / e^- / $^{0}_{-1}e$;
$\bar{\nu}$; ***[2]***

(ii) 5.00216 MeV is equivalent to 0.00537 u;
$23.99096 = 23.98504 + 0.00537 + \text{rest mass of particle}$;
rest mass $= 0.00055\,u$; ***[3]***
No credit given for bald correct answer.

(c) sodium-24 has more nucleons;
and more nucleons (usually) means greater (magnitude of) binding energy;

or

sodium-23 has less nucleons;
and less nucleons (usually) means less (magnitude of) binding energy; ***[2]***

A4. (a) product of normal component of magnetic field strength and area that it links / *OWTTE*;
$\phi = BA\cos\theta$; ***[2]***

(b) rate of change of flux $=\left(1.8\times10^{-3}\times5.0\times10^{-2}\right)=9.0\times10^{-5}\left(\text{Wb s}^{-1}\right)$;
recognize that e.m.f. $=$ rate of change of flux $=9.0\times10^{-5}\,\text{V}$; ***[2]***
Ignore any sign.

SECTION B

B1. Part 1 Momentum and energy

(a) (impulse =) force × time for which force acts;
impulse $\left(F\Delta t\right)$ = change in momentum $\left(\Delta p\right)$; ***[2]***

(b) *The following points are needed for maximum marks.*
from Newton 3;
when objects are in contact, the forces exerted by the objects on each other are equal and opposite;
from Newton 2 / collision time is the same;
impulses are equal and opposite;
therefore changes in momentum are equal and opposite / total change in momentum is zero;

or

Accept algebraic solution.
from Newton 3;
$F_{AB} = -F_{BA}$;
from Newton 2;
$F_{AB}\Delta t = m_{\mathrm{A}}\Delta v_{\mathrm{A}}$;
$= -m_B \Delta v_B$; ***[5]***

(c) (i) $v = \sqrt{2gh}$;
to give $v = 2.2\ \mathrm{m\ s^{-1}}$; ***[2]***
Award full marks for bald correct answer.

(ii) from conservation of momentum / $V \times 5.2 \times 10^{-3} = 0.38 \times 2.2$;
$V = \frac{0.38 \times 2.2}{5.2 \times 10^{-3}}$;
to give $V = 160\ \mathrm{m\ s^{-1}}$ ***[2]***

(iii) KE before $= \left(\frac{1}{2} \times 5.2 \times 10^{-3} \times 1.6^2 \times 10^4\right) = 67\ \mathrm{J}$;
KE after $= \left(\frac{1}{2} \times 0.38 \times 4.8\right) = 0.91\ \mathrm{J}$ / $(0.38 \times 9.8 \times 0.24) = 0.91\ \mathrm{J}$;
lost energy $= 66\ \mathrm{J}$; ***[3]***

(d) energy to increase from $20\ ^\circ\mathrm{C}$ to $330\ ^\circ\mathrm{C} = (5.2 \times 10^{-3} \times 130 \times 300) = 200\ (\mathrm{J})$;
energy to melt pellet $= (5.2 \times 10^{-3} \times 870) = 4.5\ (\mathrm{J})$;
total KE $= 210\ \mathrm{J}$;
$\frac{1}{2}mv^2 = 210$;
to give $v = 280\ \mathrm{m\ s^{-1}}$; ***[5]***

B1. Part 2 Gravitation

(a) force between two point / small masses;
is proportional to the product of the masses;
and inversely proportional to the square of their separation; ***[3]***

Accept formula $F \propto \frac{m_1 m_2}{r^2}$ *but full marks only if all terms are defined e.g.* m_1 *and* m_2 *are point masses, r is their separation, F is the force between the point masses (and G is a constant if "F=" used).*

(b) recognize that $g = \frac{GM}{R^2}$;

$M = \frac{gR^2}{G} = \left(\frac{6.0\times10^{-3}\times1.5^2\times10^{22}}{6.7\times10^{-11}}\right)$;

$= 2.0\times10^{30}$ kg; ***[3]***

Award ***[1 max]*** *for use of* $G\frac{M}{R}\left(=1.4\times10^{19}\right)$.

(c) $\frac{v^2}{R} = \frac{GM}{R^2}$;

$v = \frac{2\pi R}{T}$;

$\frac{4\pi^2 R^2}{T^2} = \frac{GM}{R}$;

hence $T^2 = \frac{4\pi^2 R^3}{GM}$;

recognize $\frac{4\pi^2}{GM}$ is a constant; ***[5]***

B2. Part 1 Waves

(a) Transverse

the particles (of the medium) vibrate at right angles;
to the direction of energy transfer;

Longitudinal

the particles (of the medium) vibrate in the same direction as the direction of energy transfer; ***[3]***

(b) (i) time period = 0.13 s;

$\left(f = \frac{1}{T} = \frac{1}{0.13}\right) = 7.7\,(\pm 0.3)\text{ Hz}$; ***[2]***

Award full marks for bald correct answer.

(ii) 8 mm; ***[1]***

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

$\frac{15}{7.7}$;

$\lambda = 1.95\text{ cm} \approx 2.0\text{ cm}$ ***[2]***

(d) start at $(-1.2 \rightarrow -2.0)$ on y-axis;
sine curve of amplitude 8 mm;
wavelength 2 cm; ***[3]***

(e) use of $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$

$\sin\theta_2 = \frac{v_2}{v_1}\sin\theta_1$;

$= \frac{20}{15}\sin 30$ to give $\theta_2 = 42^\circ$;

angle $= 48^\circ$; ***[3]***

(f) (i) each slit acts as a point source of waves;
waves from these sources interfere;
because of the principle of superposition;
where a trough of one wave meets a crest of another the resultant displacement will be minimum / waves arrives with opposite phase/completely out of phase / so destructive interference occurs; ***[4]***

(ii) $D = \frac{ds}{\lambda}$;
$= \frac{18 \times 9.4}{2.0}$;
= 85 / 90 cm; ***[3]***
Award full marks for bald correct answer.

(g) (i) the phase difference between them is constant; ***[1]***

(ii) fringes of equal intensity / intensity reducing from centre fringe;
and equal width; ***[2]***
[max 1] *if fringes do not touch axis.*

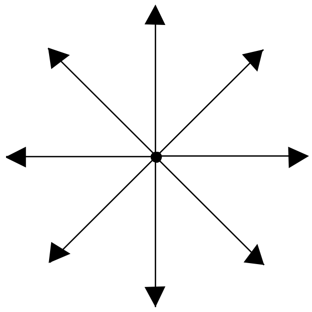
B2. Part 2 Magnetic fields

(a) effective current in each side of coil = 20I;
each wire needs to produce $\frac{1}{4}B$;
$I = \frac{2\pi rB}{\mu_0}$;
$= \frac{2\pi \times 0.6 \times 7.0 \times 10^{-5}}{4\pi \times 10^{-7} \times 80}$;
$= 2.6\text{A}$ ***[4]***
Accept correct substitution for I into $B = \frac{\mu_0 I}{2\pi r}$ *to show that* $B = 7.0 \times 10^{-5}\,T$

(b) plane vertical;
plane normal to Earth field; ***[2]***

B3. Part 1 Fields and electric charge associated with atoms

(a) (i)



at least 6 symmetric radial lines as shown <u>touching the proton</u>;
correct direction; ***[2]***

(ii) use of $E = k\frac{q}{r^2}$

$E = \frac{9.0\times10^{9}\times1.6\times10^{-19}}{25\times10^{-22}}$;

$= 5.8\times10^{11}\,\mathrm{N\,C^{-1}}$; ***[2]***

Award full marks for bald correct answer.

(b) (i) use of $F = qE$

$F = 1.6\times10^{-19}\times5.8\times10^{11}$;

$= 9.3\times10^{-8}\,\mathrm{N}$ ***[1]***

Allow use of force law.

(ii) recognize that $F = \frac{mv^2}{r}$;

$\frac{1}{2}mv^2 = \frac{1}{2}Fr$;

$= \frac{1}{2}\times9.3\times10^{-8}\times5.0\times10^{-11}$;

$= 2.3\times10^{-18}\,\mathrm{J}$ ***[3]***

(c) (i) the work required per unit charge;
to bring a small positive charge / positive test charge / positive point charge from infinity to the point; ***[2]***

(ii) PE of electron $= -\frac{e^2}{4\pi\varepsilon_0 r}$;

$= -4.6\times10^{-18}\,\mathrm{J}$; ***[2]***

Award full marks for bald correct answer.

(d) total energy required $= -4.6\times10^{-18} + 2.3\times10^{-18}$ J;

$= -\dfrac{2.3\times10^{-18}}{1.6\times10^{-19}} = 14\ (\text{eV})$; ***[2]***

(e) the power supplied per unit current / the energy supplied per unit charge; ***[1]***

(f) (i) $R = \left(\dfrac{6.0}{0.2}\right) = 30\,\Omega$; ***[1]***

(ii) $P = (6.0\times0.2) = 1.2$ W; ***[1]***

(g) (i) $I = \left(\dfrac{6.0}{15}\right) = 0.40$ A; ***[1]***

(ii) total current in the circuit 0.60 A;
resistance of parallel circuit $= 10\,\Omega$ / lost volts $= 5.0\times0.6$;
total resistance in circuit $= 15\,\Omega$ / lost volts $= 3$ V;
e.m.f. $= (0.60\times15) = 9$ V;

or

total current $= 0.60$ A;
pd across $\text{R} = 6.0$ V;
e.m.f. $= 6.0 + 0.60\times5.0$;
$= 9.0$ V; ***[4]***

B3. Part 2 Thermodynamics

(a) heat pump uses work to transfer thermal energy / heat from a cold to a hot reservoir;
heat engine transfers thermal energy into work; ***[2]***

(b) (i) work done $=(P\Delta V)=1.2\times10^{6}\times0.3=3.6\times10^{5}\,(\text{J})$;
recognize that since $\Delta U=0$ then work done $=\Delta Q$;
$\Delta Q=3.6\times10^{5}\,\text{J}$ ***[2]***

(ii) $eff=1-\dfrac{Q_{\text{out}}}{Q_{\text{in}}}$;

$0.32=1-\dfrac{3.6\times10^{5}/10^{6}}{Q_{\text{in}}}$;

to give $Q_{\text{in}}=5.3\times10^{5}$ / 10^{6} J; ***[3]***

(iii) work done $=1.8/1.7\times10^{5}$/ 10^{6} J; ***[1]***

B4. Part 1 Power and an ideal gas

(a) the rate of working / $\dfrac{\text{work}}{\text{time}}$; ***[1]***
Ratio or rate must be clear.

(b) let $\Delta s=$distance moved in time Δt such that $v=\dfrac{\Delta s}{\Delta t}$;

$P=\dfrac{\text{work}}{\text{time}}=\dfrac{F\Delta s}{\Delta t}$;
$=Fv$ ***[2]***

All symbols must be defined for full marks.

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

(ii) recognize that F= rate of change of momentum;
$\left(=\frac{\Delta m}{\Delta t}v\right)=(60\times 2.0)=120\text{ N}$; ***[2]***

(iii) $(P=120\times 2.0)=240\text{ W}$; ***[1]***

(iv) $K=\frac{1}{2}\frac{\Delta m}{\Delta t}v^2$;
$=\left(\frac{1}{2}\times 60\times 4.0\right)=120\text{ W}$; ***[2]***
Award full marks for bald correct answer.

(v) the sand on the conveyor belt must slip to be accelerated;
in slipping kinetic energy is dissipated / lost as internal energy / heat in the sand and conveyor belt;

or

there is friction between the sand and conveyor belt;
therefore kinetic energy is dissipated / lost as internal energy / heat in the sand and conveyor belt; ***[2]***
Award zero for bald statement "energy is lost as heat".

(d) temperature:
the molecules gain energy by collision with the moving piston;
therefore average KE of the molecules increases;
temperature is a measure of average KE of the molecules (so temperature increases);

pressure:
pressure is caused by the force that the molecules exert on collision with the walls of the cylinder;
the volume is decreased so there are more molecules per unit volume / more collisions per unit time;
increased temperature means greater speed;
rate of change of momentum per unit area is greater; ***[7]***

B4. Part 2　The photoelectric effect

(a) negative;
the electrons emitted from P have a certain maximum energy;
they will be repelled by plate Q / *OWTTE*;
if the maximum KE is less than the energy required for an electron to move between P and Q / less than the pd per unit charge it will not reach Q; ***[4]***

(b) light consists of photons each of energy $E = hf$;
where h is the Planck constant and f is the frequency (of the light);
the greater the frequency (of the incident light) the greater the energy of the emitted electrons / electrons now have sufficient energy to overcome the potential barrier / *OWTTE*; ***[3]***

(c) the energy of each photon is increased;
therefore for same intensity there are less photons; ***[2]***

(d) $h = \frac{E_{K_{max}} + \phi}{f}$;

$= \frac{(8.0 + 4.4) \times 1.6 \times 10^{-19}}{3.0 \times 10^{15}}$;

$= 6.6 \times 10^{-34}$ J s; ***[3]***

Must show working for full credit.

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[1]

H4. (a) first diffraction minimum at $\theta = 4.25 \times 10^{-3}$ rad
$\lambda \approx b\theta = 1.2 \times 10^{-4} \times 4.25 \times 10^{-3} = 5.1 \times 10^{-7}$ m; ***[1]***
Accept answers in the range 5.0×10^{-7} m *to* 5.2×10^{-7} m.

(b) central maximum (of any height) and width less than that of the single slit central maximum;
one secondary maximum (at approximately $\pm 2.1 \times 10^{-3}$ rad) within the enveloping single slit pattern; ***[2]***