T12-1 *[228 marks]*

1. *[1 mark]*

Markscheme

B

Examiners report

[N/A]

2. *[1 mark]*

Markscheme

D

Examiners report

[N/A]

3. *[1 mark]*

Markscheme

D

Examiners report

[N/A]

4. *[1 mark]*

Markscheme

C

Examiners report

[N/A]

5. *[1 mark]*

Markscheme

C

Examiners report

[N/A]

6a. *[8 marks]*

Markscheme

(i) use of $M \times 4.2 \times 10^3 \times \Delta\theta$;

$ml = 75 \times 10^{-3} \times 3.3 \times 10^5$ / 24750 J;
recognition that melted ice warms and water cools to common final temperature;
3.4°C;

(ii) work done on water by dropping cubes / negligible work done;
W negative or unchanged;
water gives thermal energy to ice;
Q negative;
water cools to a lower temperature;
ΔU negative / *U* decreases;

Examiners report

[N/A]

6b. *[3 marks]*

Markscheme

bright and dark rings/circles / circular fringes;
maximum and minimum / constructive and destructive;
mention of interference / mention of superposition;
link to interference being characteristic of waves;

Examiners report

[N/A]

6c. *[5 marks]*

Markscheme

(i) ($p = m_e v =$) 3.28×10^{-23}Ns;

$\lambda = \left(\frac{\text{h}}{\text{p}} = \frac{6.63 \times 10^{-34}}{3.28 \times 10^{-23}} = \right) 2.02 \times 10^{-11}\text{m}$;

(ii)
$E = \left(\frac{\Delta V}{\Delta x}\right) = \frac{3.7 \times 10^3}{22 \times 10^{-3}} \left(= 1.68 \times 10^5\right) \text{Vm}^{-1}$;
$F = (Eq) = 1.68 \times 10^5 \times 1.6 \times 10^{-19} = \left(2.69 \times 10^{-14}\right) \text{N}$;
$a = \frac{F}{m} = \left(\frac{2.69 \times 10^{-14}}{9.11 \times 10^{-31}}\right) = 2.95 \times 10^{16} \text{ms}^{-2}$;

or

use of appropriate equation, eg $v^2 = u^2 + 2as$;
correct substitution (ignoring powers of ten);
$a = 2.95 \times 10^{16}$ ms^{-2}

Examiners report

[N/A]

6d. *[2 marks]*

Markscheme

square of amplitude (of wavefunction);
(proportional to) probability of finding an electron (at a particular point);

Examiners report

[N/A]

6e. *[2 marks]*

Markscheme

relates position to momentum (or velocity);
large uncertainty in momentum / most information on momentum is lost;

Examiners report

[N/A]

7a. *[2 marks]*

Markscheme

(i) 208;

(ii) 81;

Examiners report

[N/A]

7b. *[2 marks]*

Markscheme

because the half-life is (only) 55 s;
radon is produced slowly but decays quickly (so cannot build up);

Examiners report

[N/A]

7c. *[6 marks]*

Markscheme

(i) $\left(\lambda = \frac{\text{In2}}{\text{T}_{\frac{1}{2}}} = \frac{0.693}{10.6} =\right) 6.5 \times 10^{-2}\text{hour}^{-1}$

(ii) use of λ from (h)(i);

correct substitution into $N = N_0 e^{-\lambda t}$;

8.0 to 8.3 × 10^{-4} kg;

(iii) the rate of decay/activity of polonium/radium;
is greater than the rate of decay/activity of lead;

Examiners report

[N/A]

8.

[4 marks]

Markscheme

(i) $^{235}_{92}\mathrm{U} \rightarrow ^{231}_{90}\mathrm{Th} + ^{4}_{2}\alpha$; *(allow He for α; treat charge indications as neutral)*

(ii) $\lambda = \frac{\ln 2}{7.0\times10^{8}} \left(= 9.9\times10^{-10}\mathrm{year}^{-1}\right)$;

$m_0 = 5.6\mathrm{e}^{3.9\times10^{9}\times9.9\times10^{-10}}\ (\mathrm{mg})$

266 mg; } *(unit must match eg: allow 266 mg or 0.226 g but not 266 g or 0.266 kg)*

or

number of half-lives $= \left(\frac{3.9\times10^{9}}{7\times10^{8}} =\right) 5.57$

initial mass = $5.6\times2^{5.57}$;

266 mg; } *(unit must match eg: allow 266 mg or 0.226 g but not 266 g or 0.266 kg)*

*Award **[3]** for a bald correct answer.*

Examiners report

[N/A]

9a.

[8 marks]

Markscheme

(i)
$l = \frac{\pi d^2 R}{4\rho}$ seen / correct substitution
into equation:
$24 = \frac{l\times1.7\times10^{-8}}{\pi\times\left(0.15\times10^{-3}\right)^2}$; } *(condone use of r for $\frac{\mathrm{d}}{2}$ in first alternative)*
99.7 (m);
*Award **[2]** for bald correct answer.*
*Award **[1 max]** if area is incorrectly calculated, answer is 399 m if conversion to radius ignored, ie: allow ECF for second marking point if area is incorrect provided working clear.*

(ii) electric field=
$\left(\frac{12}{99.7} =\right) 0.120\ \left(\mathrm{Vm}^{-1}\right)$; *(allow ECF from (a)(i))*
electric force=($e\times E$=$0.120\times1.6\times10^{-19}$ =)1.92×10^{-20}(N);
acceleration
$= \left(\frac{F}{m} = \frac{1.92\times10^{-20}}{9.1\times10^{-31}} =\right) 2.11\times10^{10}\left(ms^{-2}\right)$; } *($5.27\times10^{9}$ if radius used in (a)(i) allow as ECF)*

or

work done on electron = (Vq =)$12\times1.6\times10^{-19}$;

energy gained by electron = $m_e\times a\times$distance travelled = $9.11\times10^{-31}\times a\times 99.8$;

2.11×10^{10} (ms^{-2});

*Award **[3]** for a bald correct answer.*

(iii) free electrons collide with ions and other electrons;
speed decreases during collisions / transfer their kinetic during collisions;
kinetic energy transferred to heat / wires have resistance;
and speed increases/acceleration until next collision;

Examiners report

[N/A]

9b. *[7 marks]*

Markscheme

(i) use of total resistance = 11Ω; *(can be seen in second marking point)*
$\frac{1}{11} = \frac{1}{R} + \frac{1}{24}$;
20.3(Ω);

(ii) as current is same in resistor network and cell and resistance is same, half of emf must appear across resistor network;
6.0 (V);

or

$I = \frac{12}{(11+11)} = 0.545\,(\mathrm{A})$;
V=(0.545×11=) 6.0(V);

Other calculations are acceptable.
*Award **[2]** for a bald correct answer.*

(iii) pd across 2Ω=6.0V; *(allow ECF from(b)(ii))*
$\left(\frac{V^2}{R} = \frac{36}{24} =\right) 1.5\,(\mathrm{W})$;
*Award **[2]** for a bald correct answer.*

Examiners report

[N/A]

9c. *[1 mark]*

Markscheme

measure of the probability of finding an electron (at a particular place and time);

Examiners report

[N/A]

9d. *[9 marks]*

Markscheme

(i)

$\Delta p = \frac{h}{4\pi\Delta x}$ and Δx=2.0×10^{-10}; *(both needed)*

2.64×10^{-25}(Ns); *(also accept 5.28×10^{-25}(Ns))*

*Award **[2]** for a bald correct answer.*

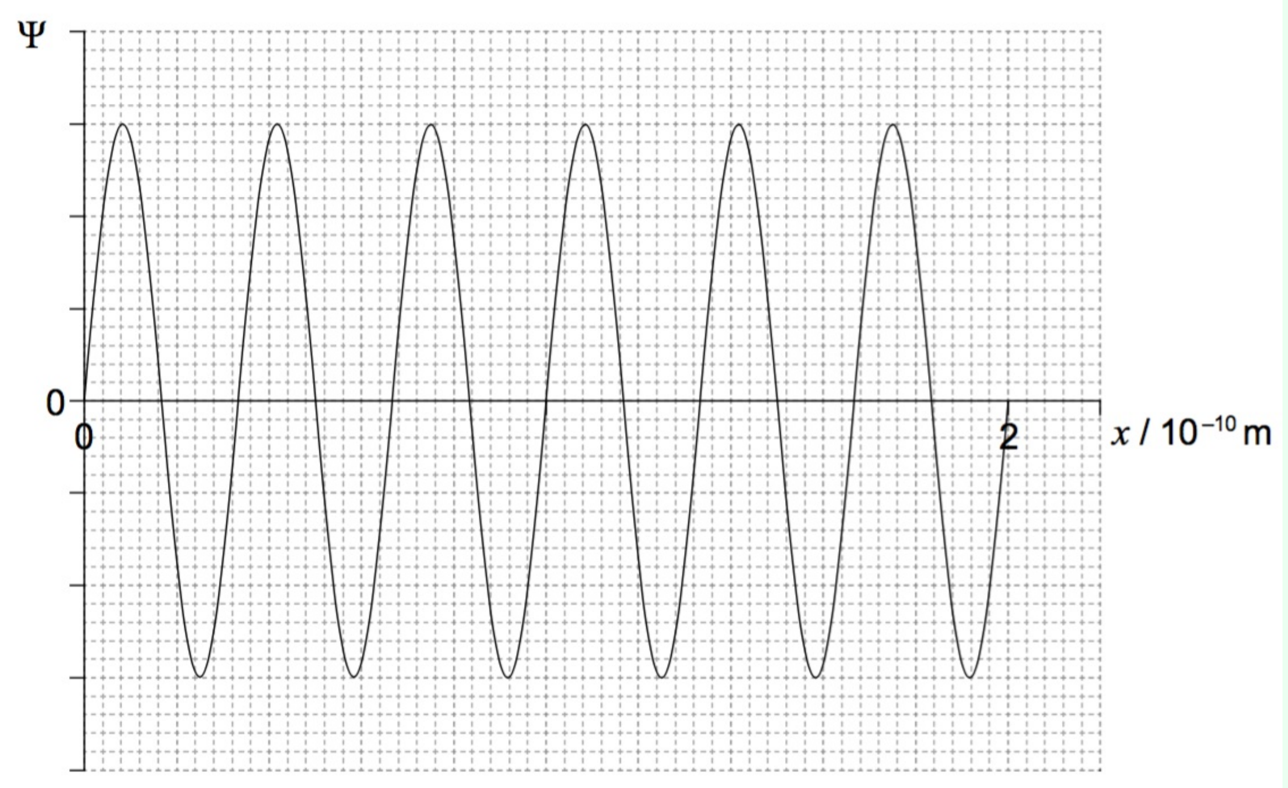
(ii)

$\lambda = \frac{h}{p}\left(= \frac{6.63\times10^{-34}}{2\times10^{-23}}\right)$;

3.3×10^{-11} (m);

*Award **[2]** for a bald correct answer.*

(iii)



periodic behaviour shown anywhere between 0 nm and 0.2 nm;

6 loops/repetitions shown anywhere between 0 nm and 0.2nm; } *(allow ECF for division of 2×10^{-10} by answer to d(ii))*

wavefunction completely fills from 0 nm to 0.2 nm and does not go beyond;

(iv) amplitude of Ψ/graph;

squared;

Examiners report

[N/A]

10a. *[1 mark]*

Markscheme

minimum energy/work required to remove an electron (from the surface of the substance);

Examiners report

[N/A]

10b. *[2 marks]*

Markscheme

$f_{min} = \frac{2.9 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = \left(7.0 \times 10^{14}\right) \text{(Hz)};$

$\lambda_{max} = \left(\frac{3.00 \times 10^{8}}{7.0 \times 10^{14}}\right) = 4.3 \times 10^{-7} \text{ (m)};$

Examiners report

[N/A]

10c. *[2 marks]*

Markscheme

$p = \left(\frac{h}{\lambda_{max}} =\right) \frac{6.63 \times 10^{-34}}{4.3 \times 10^{-7}};$

$=1.5 \times 10^{-27}$ (kg ms^{-1});

Allow ECF from (b).

or

$p = \left(\frac{\phi}{c} =\right) \frac{2.9 \times 1.6 \times 10^{-19}}{3.00 \times 10^{8}}$

$=1.5 \times 10^{-27}$ (kg ms^{-1});

Allow ECF from (b).

Examiners report

[N/A]

11a. *[3 marks]*

Markscheme

spectrum of beta decay is continuous;

with a maximum value of energy;

the resulting energy difference between energy of any $\beta^{(+)}$ and maximum $\beta^{(+)}$ energy is accounted for by the energy of the neutrino / reference to energy difference between parent energy level and excited energy level of daughter;

Examiners report

[N/A]

11b. *[2 marks]*

Markscheme

$\mathrm{T}_{\frac{1}{2}} = \frac{\text{In}2}{0.061} = 11.4 \text{ (s)};$

$\left(N = \frac{1}{8}N_0 \text{ so}\right) t = \left(3T_{\frac{1}{2}} =\right) 34 \text{ (s)}$

or

$t = -\frac{\text{In}0.125}{0.061};$

t=34(s);

Examiners report

[N/A]

12a. *[5 marks]*

Markscheme

(i) photon energy

$= \left(\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{450 \times 10^{-9}} = \right) 4.4 \times 10^{-19} \text{ (J)};$

=2.76(eV) ;

2.76 - 2.4 = 0.36 (eV) ;

*Award **[3]** for a bald correct answer.*

*Award **[1 max]** if the energy of the photon is not converted from Joules to eV (giving E_K=-2.4 eV).*

(ii) $2 \times 10^{15} \times 1.6 \times 10^{-19}$;

3×10^{-4} (A);

*Award **[2]** for a bald correct answer.*

Examiners report

In part (a)(i) many correct answers were seen, however there were quite a few mistakes in converting the photon energy to eV. Part (a)(ii) was easy, but some candidates thought that the KE of the electrons needed to be used.

12b. *[4 marks]*

Markscheme

light consists of photons;
frequency of photons increases so energy of photons increases;
same intensity of radiation means fewer photons;
fewer photons means fewer (photo)electrons;
(the emitted number of electrons falls)

Examiners report

Candidates found (b) difficult as the answer is slightly counter-intuitive. Very few candidates seemed to know that equal intensity of light means equal total photon energy per second. Many assumed it meant equal number of photons per second. The answers were mostly disorganised and did not reflect a logical scientific argument that would be expected at this level.

13a. *[4 marks]*

Markscheme

measurement of mass of sample / determination of molar mass;
determination of number of nuclei *N*;
measurement of activity *A*;
determination of decay constant from

$\lambda = \frac{A}{N};$

half-life from

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda};$

Examiners report

Most candidates were very uncertain about determining a very long half-life. Part marks were often obtained for stating how half-life was obtained from the decay constant, but determination of activity and number of sample atoms was not usually mentioned. Most candidates described how the half-life of a nuclide with a short half-life can be found.

13b. *[3 marks]*

Markscheme

$\lambda = \left(\frac{\ln 2}{T_{\frac{1}{2}}} = \frac{\ln 2}{9000} =\right) 7.70 \times 10^{-5} \text{yr}^{-1}$;

$m = \left(m_0 e^{-\lambda t} =\right) 1.8 \times e^{-7.70 \times 10^{-5} \times 25000}$;

m=0.26 (kg);

or

$\frac{25000}{9000} = 2.77$ half-lives;

fractional mass left =

$\left(\frac{1}{2}\right)^{2.77} = 0.15$;

mass left=1.8×0.15=0.26 (kg);

*Award **[3]** for a bald correct answer.*

Examiners report

In (b) surprisingly few candidates know the easy way to calculate fraction remaining. Find the number of half-lives passed (n). Fraction remaining = 0.5^n. This works even when n is non-integer. Most obtained at least 1 mark for finding the decay constant or the number of half-lives. Quite a few candidates assumed a proportional relationship for the non-integer part of n.

14. *[1 mark]*

Markscheme

B

Examiners report

[N/A]

15. *[1 mark]*

Markscheme

C

Examiners report

This question did involve careful reading. The statistics would suggest that many candidates rushed the question and guessed the answer. The question was not asking which of the statements was true – but rather which of them showed that light consists of photons. Clearly I will be true if light is either a wave or photonic, so D, the most popular answer, must be incorrect.

16. *[1 mark]*

Markscheme

B

Examiners report

This was a very good discriminator – but involved a lot of guessing for the weaker candidates.

Candidates should be familiar with the de Broglie wavelength increasing as the speed of the particle increases, so C and D can be eliminated immediately. And, in calculating the change in wavelength (which they do not need to do) the equation kinetic energy = potential energy will be used. This involves the square of the velocity, hence B must be true.

17.

[1 mark]

Markscheme

D

Examiners report

[N/A]

18.

[1 mark]

Markscheme

B

Examiners report

[N/A]

19.

[1 mark]

Markscheme

B

Examiners report

[N/A]

20.

[1 mark]

Markscheme

A

Examiners report

[N/A]

21.

[1 mark]

Markscheme

B

Examiners report

The most popular responses were A and C, both of which are incorrect. One can only assume that the candidates did not read the question with sufficient care and, on seeing the words “metal” and “electrons”, automatically assumed the photoelectric effect was involved.

22.

[1 mark]

Markscheme

A

Examiners report

A simple diagram showing the depletion of the sample with increasing half-lives is needed. Those who chose B were perhaps jumping to conclusions without such a visual image.

23a. *[2 marks]*

Markscheme

one twelfth of the mass of a carbon-12 atom/ ${}^{12}_{6}\mathrm{C}$;
Do not allow nucleus.

255.09×931.5 = 237600$(\mathrm{MeV}c^{-2})$;
*Award **[1]** for a bald correct answer.*

Examiners report

i) The definition of the unified atomic mass unit relates to the mass of the carbon 12 atom. Few candidates made this reference.

ii) Almost all were able to convert the mass unit into $\mathrm{MeV}c^{-2}$.

23b. *[6 marks]*

Markscheme

(i) neutron/${}^{1}_{0}\mathrm{n}$;

(ii) the (rest) mass of the products is greater than that of the reactants;
energy must be given to supply this extra mass;

(iii) $\Delta m = [37216.560 + 938.272] - [37214.694 + 939.565] = 0.573\ (\mathrm{MeVc^{-2}})$;
energy required for reaction=0.573(MeV);
kinetic energy=(8.326-0.573=)7.753(MeV);
*Award **[3]** for a bald correct answer.*

Examiners report

i) This was well answered with the majority of candidates identifying the neutron.

ii) Few could relate the mass defect to the energy required to initiate the reaction.

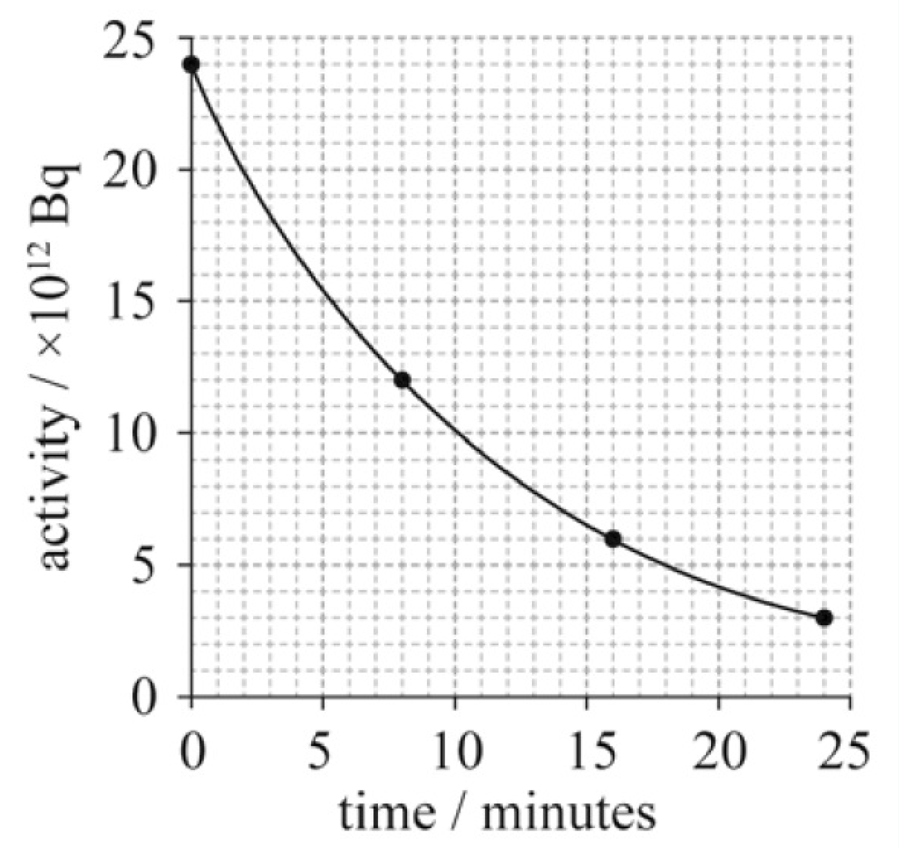
iii) Many were able to calculate the mass defect but did not realize that in this reaction it is the energy needed to initiate the reaction. This is why the products have more combined mass than the reactants.

23c. *[5 marks]*

Markscheme

(i) time for the activity of a sample to halve / time for half the radioactive nuclei to decay;

(ii) four data points (0, 24) (8, 12) (16, 6) (24, 3) correct;
smooth curve through points;



(iii) 2 hours (=120 minutes)=15 half-lives;
activity=$\frac{24\times10^{12}}{2^{15}} = 7.3\times10^{8}\ (\mathrm{Bq})$;

or

$\lambda = \frac{\ln 2}{8}$; $\left(A = A_0 e^{-\lambda t}\mathrm{method}\right)$;
=7.3×10^{8}(Bq)

*Award **[2]** for a bald correct answer.*

Examiners report

i) The definition of radioactive half-life was often poorly done with few appreciating that half the radioactive nuclei decay into a more stable form. Those that explained that the activity of the sample would halve were more successful.

ii) Almost all were able to draw the decay curve.

iii) This was well answered with responses split between those that successfully found the number of half-lives elapsed in 2 hours and going on to find the activity of the sample and those that took the decay constant route. At SL, most successfully found the number of half lives elapsed in 2 hours and were able to find the corresponding activity of the sample.

23d. *[5 marks]*

Markscheme

(i) the energy (absorbed/released) when a unit mass/one kg;
of liquid freezes (to become solid) at constant temperature / of solid melts (to become liquid) at constant temperature;

(ii) potential energy changes during changes of state / bonds are weakened/broken during changes of state;
potential energy change is greater for vaporization than fusion / more energy is required to break bonds than to weaken them;
SLH vaporization is greater than SLH fusion;
Only award third marking point if first marking point or second marking point is awarded.

Examiners report

i) The majority related the latent heat to the energy required for a change of state but few successfully completed the definition by explaining that fusion is the change of state between a solid and liquid at constant temperature.

ii) This explanation was poorly done with few gaining full marks. Few could relate the change in potential energy during a change of state to fusion and vaporization.

23e. *[5 marks]*

Markscheme

(i) use of $\Delta Q = mc\Delta T$ and mL;
$0.020 \times 3.3 \times 10^5 + 0.020 \times 4200 \times (T - 0) = 0.25 \times 4200 \times (80 - T)$;
T=68(°C);
*Allow **[3]** for a bald correct answer.*
*Award **[2]** for an answer of T=74°(C) (missed melted ice changing temperature).*

(ii) no energy given off to the surroundings/environment;
no energy absorbed by beaker;
no evaporation of water;

Examiners report

i) Of those candidates that established a relevant energy transfer equation, many did not include the heat gained by the ice once it had melted.

ii) Few could state two sources of energy loss that were not included in their energy equation.

24a. *[6 marks]*

Markscheme

(i) light consists of photons/quanta/packets of energy;
(each) photon has energy $E=hf$ / photon energy depends on frequency;
a single photon interacts with a single electron giving up all its energy;
a certain amount of energy is required to eject an electron from the metal;
if photon energy is less than this energy/work function/frequency <u>below threshold</u>, no electrons are emitted;

(ii) increasing the intensity increases the photoelectric current;
photocurrent will change as a different metal has a different work function/threshold frequency;

Examiners report

fi) Many wrote essentially the same point, about threshold frequency, in a number of different ways in their answers. Examiners were surprised at how few mentioned photons.

fii) It was common to score one mark here for discussing an increase in the photocurrent but a significant number scored two marks.

24b. *[5 marks]*

Markscheme

(i) $E_K = [6.6 - 3.7] \times 10^{-19} = 2.9 \times 10^{-19}$ (J);
$E_K = \frac{p2}{2m} \Rightarrow p = \sqrt{2mE_K} = \sqrt{2 \times 9.1\,(1) \times 10^{-31} \times 2.9 \times 10^{-19}}$;
p=7.2×10^{-25}(kg ms^{-1}); *(allow answers in the range of 7.2 to 7.3×10^{-25})*
*Award **[3]** for a bald correct answer.*

(ii) $\Delta p = \frac{\frac{h}{4\pi}}{\Delta x} = \frac{\frac{6.6(3)\times10^{-34}}{4\pi}}{5.0\times10^{-9}}$;
=1.1×10^{-26}(kg ms^{-1});
*Award **[2]** for a bald correct answer.*

Examiners report

gi) This was answered well and of those that couldn't finish the calculation, most were able to calculate the kinetic energy for the first mark.

gii) The calculation in this question was tackled well by most.

25a. *[2 marks]*

Markscheme

all particles have an associated wavelength/behave like waves;
with $\lambda = \frac{h}{p}$ and symbols defined/described using terms;

Examiners report

[N/A]

25b. *[2 marks]*

Markscheme

reference to the Heisenberg uncertainty principle / $\Delta x \Delta p \geq \frac{h}{4\pi}$;
$\Delta p = 0$ implies Δx is large /$\Delta x = \infty$;

Examiners report

[N/A]

25c. *[1 mark]*

Markscheme

the (square of the) amplitude gives the probability of finding the electron at a given point in space;

Examiners report

[N/A]

26a. *[1 mark]*

Markscheme

the probability of decay of a nucleus per unit time;

Examiners report

[N/A]

26b. *[5 marks]*

Markscheme

(i) alpha particle / helium nucleus;

(ii) number of Po nuclei produced=number of Rn nuclei decayed *(seen or implied)*;
$0.5 = 1.6e^{-\lambda t}$;
$t = \left(-\frac{\ln \frac{0.5}{1.6}}{\lambda} = \right) \frac{1.163}{8.0 \times 10^{-5}}$;
1.5×10^4(s);

Examiners report

[N/A]

26c. *[3 marks]*

Markscheme

initial kinetic energy=electric potential energy at closest distance;

kinetic energy $E = \left(6.2 \times 10^6 \times 1.6 \times 10^{-19} =\right) 9.9 \times 10^{-13}\ (\mathrm{J})$;

$d = k\frac{q_1 q_2}{E} = 8.99 \times 10^9 \frac{2\times 79\times\left[1.6\times 10^{-19}\right]^2}{9.9\times 10^{-13}} (\mathrm{m})$ ***or*** $= 3.7 \times 10^{-14}\ (\mathrm{m})$;

Examiners report

[N/A]

27. *[1 mark]*

Markscheme

C

Examiners report

[N/A]

28. *[1 mark]*

Markscheme

A

Examiners report

Photons are emitted so the wavelength of the light is shorter than the threshold wavelength. Doubling the wavelength might make it greater than the threshold and so this is the only option which may result in no electrons being emitted – the intensity of light (that is, the number of photons per second) has no influence on this.

29. *[1 mark]*

Markscheme

B

Examiners report

The continuous spectrum for beta emission is the key here. A continuous spectrum is not characteristic of discrete energy levels (but alpha and gamma occur with distinct energies and therefore must be related to nuclear energy levels).

30. *[1 mark]*

Markscheme

A

Examiners report

[N/A]

31. *[1 mark]*

Markscheme

D

Examiners report

There was an issue with the Spanish translation of the stem to this question. Statement III “La energia cinetica del electron” should have corresponded to the English “The kinetic energy of the electron increases”. This statement made up part of the correct answer (D), which refers to this statement and statement I. A manual adjustment was made to the marks for each candidate to ensure no candidate was disadvantaged for this question.

The paper has been amended for publication to the correct translation of “La energia cinetica del electron aumenta”.

32. *[1 mark]*

Markscheme

C

Examiners report

[N/A]

33. *[1 mark]*

Markscheme

B

Examiners report

There was a fairly even split between response A and B for this question. This may have been caused by candidates either not reading the responses carefully enough or not appreciating the difference between the two.

34. *[1 mark]*

Markscheme

D

Examiners report

The responses showed that the majority of the candidates understood that the wavelength gets smaller with increasing speed of the electron (responses B and D). However they failed to realize that the energy given to the particle is proportional to the square of the velocity. Hence the factor of $\sqrt{2}$ is necessary when considering the momentum.

35. *[1 mark]*

Markscheme

D

Examiners report

Teachers objected to this question as there was no exact answer; however the rubric for Paper 1 invites the candidates to choose the best answer. They should be able to estimate and make approximations. In this case the best answer is obvious from a quick sketch graph. It is not necessary to use a calculator.

36a.

[1 mark]

Markscheme

minimum (photon) energy needed to eject electrons (from a surface);

Examiners report

Most candidates choosing this option were able to answer this well although a minority forgot to mention that this was the **minimum** energy needed for a photon to eject an electron from a metal surface.

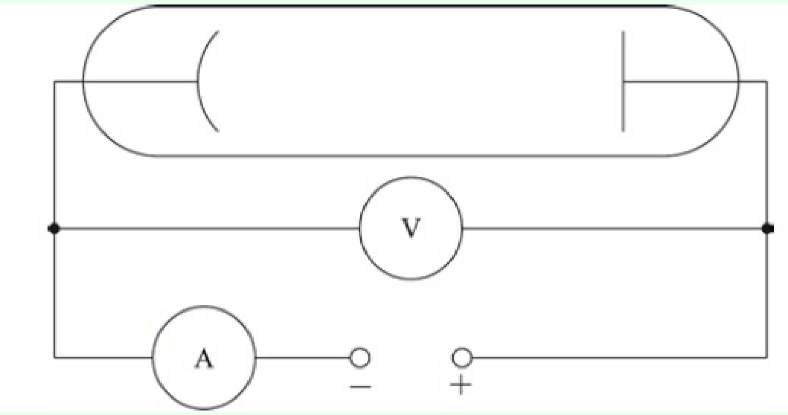
36b.

[4 marks]

Markscheme

(i) apply stopping potential / *OWTTE;*
maximum kinetic energy =*eV;*

(ii)



power supply negative connected to detector;
ammeter and voltmeter correctly connected;
Allow voltmeter connected directly across power supply.

Examiners report

(i) The technique for measuring the maximum kinetic energy of the emitted electrons was poorly known. Centres would be well advised to use a simulation if they do not have the opportunity to actually perform this experiment with a photocell.

(ii) Given that is such a simple circuit this was very badly answered with many ‘circuits’ not being circuits at all – in essence, ignoring the polarity needed for the cell, this is a simple resistance measuring circuit. Few realised that the detector must have a negative voltage to prevent the electrons from reaching it.

36c.

[2 marks]

Markscheme

more intense light means more photons per second;
so more electrons are ejected (per second);

Examiners report

Only those candidates approaching this by relating the intensity of light to the number of incident photons per second tended to be successful here. By stating this it was a simple matter or recognising that there is a one to one correspondence between photons and electrons so more intense light inevitably meant more electrons emitted per second. Many wasted time in explaining why emission of electrons meant that the incident light had a frequency higher than the threshold frequency.

37a. *[3 marks]*

Markscheme

atomic spectra have discrete line structures / only discrete frequencies/wavelengths;
photon energy is related to frequency/wavelength;
photons have discrete energies;
photons arise from electron transitions between energy levels;
which must have discrete values of energy;

Examiners report

(a) Candidates struggled with this question. Although they demonstrated some familiarity with the idea, they could not clearly describe the connection between atomic structure and the emission spectra, usually discussing electrons without photons. The arguments leading from atomic spectra to energy levels were not logically organised.

37b. *[3 marks]*

Markscheme

de Broglie suggests that electrons/all particles have an associated wavelength; this wave will be a stationary wave which meets the boundary conditions of the box; the stationary wave has wavelength $\frac{2L}{n}$ (where L is the length of the box and where n is an integer);

Examiners report

There were very few correct answers to (b).

37c. *[6 marks]*

Markscheme

(i) wavelength of ψ_A larger than ψ_B;
therefore momentum of ψ_B larger than ψ_A (from de Broglie hypothesis); therefore ψ_B has larger energy;
*Award **[1 max]** for a bald correct answer.*

or

ψ_B has n=3, ψ_A has n=2;
$E_K \propto n^2$;
so ψ_B corresponds to the larger energy;

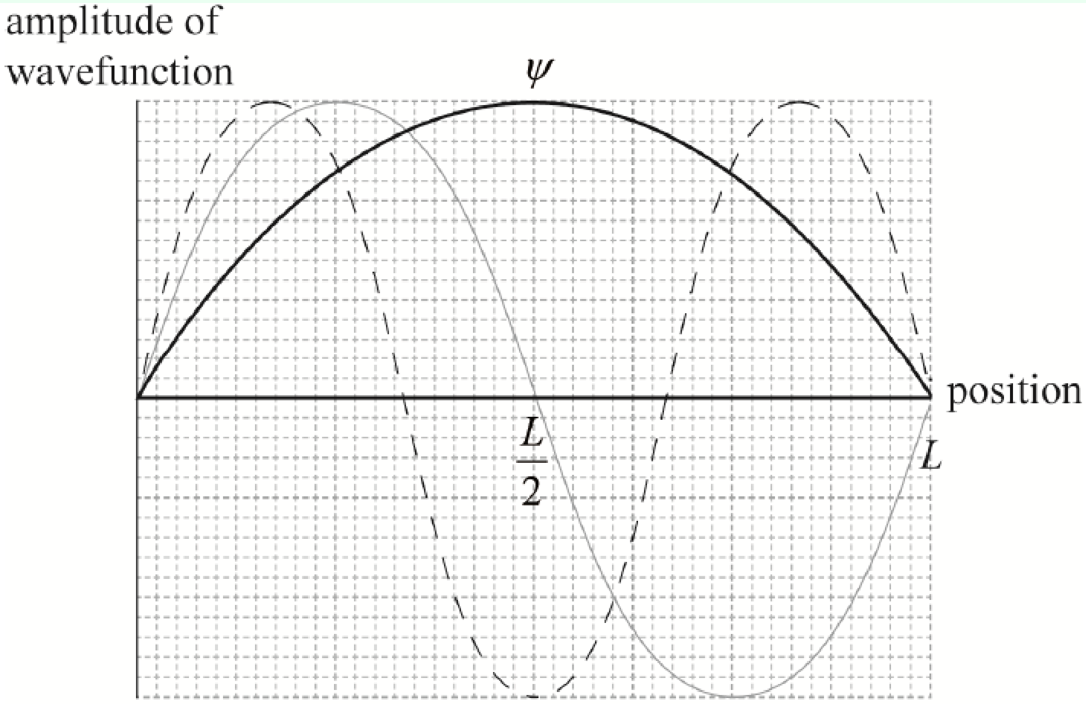
(ii) ψ_A=0, $\psi_B \neq 0$ in the middle of the box/at $\frac{L}{2}$;
so ψ_B corresponds to the larger probability since probability $\propto |\psi|^2$;
Accept $\propto \psi^2$.

or

the probability (of finding the electron) is related to the amplitude;
amplitude of ψ_B is greater than amplitude of ψ_A so ψ_B is more likely to be found;

*Award **[1 max]** for a bald correct answer.*

(iii)



correct sketch; (accept -ψ)
Accept wavefunction with any amplitude.

Examiners report

(i) was reasonably well done by many, although many did not refer to the de Broglie hypothesis explicitly and thus relate wavelength to momentum and so to energy.

(ii) was poorly answered. Not many candidates understood the relation between amplitude and probability of locating the particle.

(iii) was well done by most.

38a. *[3 marks]*

Markscheme

$^{22}_{11}\text{Na} \rightarrow ^{22}_{10}\text{Ne} + ^{0}_{+1}e + ^{0}_{0}v$

$^{22}_{10}\text{Ne}$;

$^{0}_{+1}e$ (*accept* $^{0}_{+}e$)

$^{0}_{0}v$; (*award* ***[0]*** *for* $^{0}_{0}\overline{v}$)

Examiners report

This question was well done in general.

38b. *[1 mark]*

Markscheme

time taken for half/50% of the nuclei to decay / activity to drop by half/50%;

Examiners report

Many candidates referred to mass halving rather than activity.

38c. *[4 marks]*

Markscheme

(i) $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$;

$\frac{0.693}{0.27\text{yr}^{-1}}$=2.6 (years);

Award ***[2]*** *for a bald correct answer.*

(ii) N=5.0 x 10^{23} x $e^{-0.27 \times 5.0}$;

N=1.3 x 10^{23};

Award ***[2]*** *for a bald correct answer.*

Examiners report

39. *[1 mark]*

Markscheme

D

Examiners report

[N/A]

40a. *[3 marks]*

Markscheme

(i) the acceleration (of a particle/P) is (directly) proportional to displacement;

and is directed towards equilibrium/in the opposite direction to displacement;

Do not accept "directed towards the centre".

(ii) $\frac{\pi}{2}$/90°/quarter of a period;

Examiners report

[N/A]

40b. *[6 marks]*

Markscheme

(i) light from a hydrogen discharge tube/hot hydrogen gas/ hydrogen tube with potential difference across it;
is passed onto a prism/diffraction grating;
and then is observed on a screen/through a telescope;
Accept good labelled diagram for explanation of any marking point.

(ii) each wavelength corresponds to the energy of the photon emitted;
when an electron makes a transition from a higher to lower energy level;
since only discrete wavelengths/finite number of wavelengths are present, then only discrete energy levels are present / *OWTTE*;

Examiners report

[N/A]

40c. *[4 marks]*

Markscheme

(i) −3.40 eV;
*Award **[0]** for omitted negative sign.*

(ii) energy difference between levels$= \frac{hc}{\lambda e} = \frac{6.63\times10^{-34}\times3\times10^{8}}{4.85\times10^{-7}\times1.6\times10^{-19}}$;
=2.55eV;
$[3.40 - 2.55] = 0.85 = \frac{13.6}{n^2}$ to give n^2=16;
n=4;
*Award **[3]** for reversed argument.*

Examiners report

[N/A]

40d. *[2 marks]*

Markscheme

the total emitted energy is shared between the electron and the antineutrino;
the energy/velocity can be shared/distributed in an infinite number of ways / *OWTTE*;

Examiners report

[N/A]

41a. *[6 marks]*

Markscheme

(i) electrons in the metal require a minimum amount of energy to be ejected from the metal;
(according to wave theory) the energy of a wave is dependent on intensity and not frequency;
so given enough time to absorb energy electron emission should take place at any frequency no matter what the intensity / *OWTTE*;

(ii) photons have energy *hf*/proportional to frequency (of the light);
an electron may be ejected if this energy is equal to or greater than a threshold value/work function;
the intensity determines the rate of release of photoelectrons, but not their energy;

Examiners report

[N/A]

41b. *[5 marks]*

Markscheme

(i) recognize that slope of graph$=\frac{h}{e}$ ***or*** *h* (in eV s);

evidence of finding slope eg. $\frac{0.5}{[6.8-5.6]\times10^{14}}=4.17\times10^{-15}$; } (accept values in the range of 4.0 to 4.2×10^{-15})

$h=1.6\times10^{-19}\times4.17\times10^{-15}=6.7\times10^{-34}$ (Js); } (accept values in the range of 6.4 and 6.7×10^{-34}(Js))

*Award **[0]** for an unsupported correct answer.*

(ii) threshold frequency=5.6×10^{14}(Hz);

work function (hf_0)=6.63×10^{-34}×5.6×10^{-14}=3.7×10^{-19}(J) ***or*** 2.3(eV);

*If necessary award **[2]** for use of ECF value of h from (b)(i).*

*Award **[2]** for use of any data point and W=hf-Ek giving an answer of 3.7(±0.1)×10^{-19}(J).*

*Award **[2]** for a bald correct answer.*

Examiners report

[N/A]

41c. *[3 marks]*

Markscheme

use $p=\frac{h}{\lambda}$ and $E_\text{K}=\frac{p^2}{2m}$ to show that $\lambda=\frac{h}{\sqrt{2mE_\text{K}}}$; *(allow equivalent working)*

electron kinetic energy=0.5×1.6×10^{-19}(J) ***or*** 8.0×10^{-20}(J);

$\lambda=\left(\frac{6.63\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times8.0\times10^{-20}}}=\right)1.74\times10^{-9}$ (m); } *(must see to three significant figures or better)*

(≈1.7×10^{-9}m)

Award marks for evidence of valid working, as the answer is given in the question.

Examiners report

[N/A]

42a. *[2 marks]*

Markscheme

$\left({}^{40}_{19}\text{K}\rightarrow{}^{40}_{18}\text{Ar}+{}^{0}_{1}\beta^{+}+v\right)$

${}^{40}_{18}\text{Ar}$;

v; (do not accept $\overline{v}$)

Examiners report

[N/A]

42b.

[4 marks]

Markscheme

original number of K-40 atoms=$(1.6\times10^{22}+[8.4\times10^{21}\times10]=)1.0\times10^{23}$;
decay constant=$\frac{\ln 2}{1.2\times10^{9}}$ ***or*** 5.8×10^{-10}(yr^{-1});
$1.6\times10^{22}=1.0\times10^{23}\mathrm{e}^{-5.8\times10^{-10}t}$;
to give $t=3.2\times10^{9}$ (yr);
Accept any alternative method that leads to the correct answer.
*Award **[3 max]** ECF after incorrect value for N_0 (eg. use of 2.44×10^{22} to give 7.3×10^{22} yr).*
*Award **[2 max]** for approximate answers (eg. 3.0×10^{9} yr based on an estimate of between two and three half-lives.)*

Examiners report

[N/A]

43a.

[3 marks]

Markscheme

(i) probability that a nucleus decays in unit time;

(ii) $150=800e^{-1.2\times10^{-3}t}$;
1400s;

Examiners report

[N/A]

43b.

[4 marks]

Markscheme

(i) 580 s;

(ii) activity/count rate measured at regular time intervals/for at least three half-lives;
plot graph activity/count rate versus time;
detail of determination of half-life from graph;

Examiners report

[N/A]

43c.

[2 marks]

Markscheme

beta energy spectrum is continuous and associated gamma spectrum is discrete;
difference in energies accounted for by existence of another particle;

or

if another particle not present;
then momentum not conserved in beta decay;

Examiners report

[N/A]