Mark schemes

1 A

[1]

2 D

1

3 D

[1]

4 B

[1]

5 B

[1]

6 (a) electrons move(or excited) from one energy level(or orbit) to another **(1)**
emitting or absorbing a <u>definite</u> frequency / wavelength / colour **(1)**
or photon energy(of electromagnetic radiation) **(1)**

The Quality of Written Communication marks were awarded primarily for the quality of answers to this part

(2)

(b) (i) E_i = 5.2 (eV) **(1)** × 1.6 × 10^{-19}
= 8.3 × 10^{-19}(J) **(1)**
(allow e.c.f. if incorrect value of energy in eV)

(ii) ($f = \frac{c}{\lambda}$ gives) $f = \frac{3.0 \times 10^8}{6.1 \times 10^{-7}}$ **(1)**
= 4.9 × 10^{14} Hz **(1)**

(iii) ($\Delta E = hf$ gives) E = 6.63 × 10^{-34} × 4.9 × 10^{14} **(1)**
= 3.2 × 10^{-19} (J) **(1)**
(allow e.c.f. from (ii))

(iv) line drawn from **B** to **D** **(1)**

(v) D to E **(1)**

(vi) B to C **(1)**

(9)

[11]

7 (a) (i) when electrons/atoms are in their lowest/minimum energy (state) **or** most stable (state) they (are in their ground state) ✓

1

(ii) in either case an electron receives (exactly the right amount of) energy ✓

excitation promotes an (orbital) electron to **a higher energy/up a** level ✓

ionisation occurs (when an electron receives enough energy) **to leave** the atom ✓

3

(b) electrons occupy discrete energy levels ✓

and need to absorb an exact amount of/enough energy to move to a higher level ✓

photons need to have certain frequency to provide this energy **or** e = hf ✓

energy required is the same for a particular atom or have different energy levels ✓

all energy of photon absorbed ✓

in 1 to 1 interaction or clear **a/the photon** and **an/the electron**s ✓

4

(c) energy = $13.6 \times 1.60 \times 10^{-19} = 2.176 \times 10^{-18}$ (J) ✓

$hf = 2.176 \times 10^{-18}$ ✓

$f = 2.176 \times 10^{-18} \div 6.63 \times 10^{-34} = 3.28 \times 10^{15}$ Hz ✓ 3 sfs ✓

4

[12]

8

(a) (i) k.e. = $\frac{4.1 \times 10^{-18}}{1.6 \times 10^{-19}}$ **(1)**

= 26 (eV) **(1)** (25.6 eV)

(ii) (use of $\lambda_{dB} = \frac{h}{mv}$ gives) $\lambda_{dB} = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 3.0 \times 10^{6}}$ **(1)**

= 2.4×10^{-10} m **(1)** (2.42×10^{-10} m)

4

(b) (use of $hf = E_1 - E_2$ gives) $f = \frac{(0.90 - 0.21) \times 10^{-18}}{6.6 \times 10^{-34}}$ **(1)**

(= 1.05×10^{15} (Hz))

(use of $\lambda = \frac{c}{f}$ gives) $\lambda = \frac{3.0 \times 10^{8}}{1.05 \times 10^{15}}$ **(1)**

= 2.9×10^{-7} m **(1)** (2.86×10^{-7} m)

3

[7]

9 (a) (i) (use of $d \sin \theta = n\lambda$ gives) $2\lambda = d \sin 35.8°$ **(1)**

$d = \frac{1}{600 \times 10^{3}}$ (m) **(1)** (= 1.67×10^{-6})

$\lambda \left(= \frac{\sin 35.8}{2 \times 600 \times 10^{3}}\right) = 4.9 \times 10^{-7}$m **(1)** ($4.87 \times 10^{-7}$m)

(ii) $f \left(= \frac{c}{\lambda} = \frac{3.0 \times 10^{8}}{4.87 \times 10^{-7}} = 6.1(6) \times 10^{14} \text{(Hz)}\right)$

E (= $hf = 6.63 \times 10^{-34} \times 6.16 \times 10^{14}$) = 4.1×10^{-19}(J) **(1)** ($4.0(8) \times 10^{-19}$(J))

$E \left(= \frac{4.08 \times 10^{-19}}{1.6 \times 10^{-19}}\right)$ = 2.6 (eV) **(1)** (2.55 (eV)

(for $E = 4.1 \times 10^{-19}$(J) = 2.56 (eV)

5

(b) (i) from C to A **(1)**

(ii) (use of $E_k = 3/2kT$ gives) $E_k = 1.5 \times 1.38 \times 10^{-23} \times 5000 = 1.0(4) \times 10^{-19}$J

[or = 0.64(7) eV] **(1)**

(iii) some gas atoms have enough kinetic energy to cause excitation by collision **(1)**
photons (of certain energies) only released when de-excitation or electron transfer to a lower level, occurs **(1)**
gas atoms have a spread of speeds / kinetic energies **(1)**
mean E_k (of gas atoms) proportional to T **(1)**
excitation can occur to level C **(1)**
de-excitation from C to B produces 2.6 eV photon / light of this wavelength **(1)**

(max 6)
QWC 1

[11]

10 (a) lowest energy state/level that the electron can occupy

or state in which electron needs most energy to be released

B1

1

or the level of an unexcited electron (not lowest orbit)

(b) (i) force = mv^2/r or $mr\omega^2$ and $v = r\omega$

B1

$8.1 \times 10^{-8} = 9.1 \times 10^{-31} \times v^2/5.3 \times 10^{-11}$
or (v^2 =) 4.72×10^{12} seen

B1

2.17 × 106 (m s^{-1})

B1

(ii) $\lambda = h/mv$ or $6.6 \times 10^{-34}/9.1 \times 10^{-31} \times 2.2 \times 10^6$

C1

7

3.3×10^{-10} m

A1

(iii) circumference = $2\pi 5.3 \times 10^{-11} = 3.3 \times 10^{-10}$ m

M1

1 (allow e.c.f. from (ii))

A1

(c) (i) $1.9(4) \times 10^{-18}$ J

B1

(ii) 5.6×10^{-19} J (e.c.f. 2.5×10^{-18} − their (i))

B1

(iii) energy difference $E = 3 \times 10^{-19}$ J
(condone any difference)

C1

$E = hc/\lambda$ *or* $E = hf$ *and* $c = f\lambda$

or their $E = 6.6 \times 10^{-34} \times 3.0 \times 108/\lambda$

C1

6.6 or 6.7×10^{-7} m

A1

5

[13]

11 Correct substitution ignoring powers of 10 in *hc* / λ

C1

Photon energy = 3.0(3) × 10^{-19}J

Photon energy in eV = 1.9 eV gets 3 marks

A1

Conversion of −3.4 eV to J (5.44 × 10^{-19} seen)

C1

Answer −2.4 × 10^{-19} J (must have negative sign)

−8.4(8.5) × 10^{-19} J gets 3 marks

A1

[4]

12 (a) an electron is excited/promoted to a higher level/orbit **(1)**
reason for excitation: e.g. electron impact/light/energy externally applied **(1)**
electron relaxes/de-excited/falls back emitting a photon/ em radiation **(1)**
wavelength depends on the energy change **(1)**

Max 3
QWC 1

(b) (i) use of $E = hf$ gives) $E = \frac{hc}{\lambda}$ **(1)**

$$= \frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{4.0 \times 10^{-7}} = 5.0 \times 10^{-19} \text{ (J)}$$ **(1)**

(4.95 × 10^{-19} (J))

and $\left(\frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{2.0 \times 10^{-7}}\right) = 9.9 \times 10^{-19}$ (J) **(1)**

(ii) (energy of) level B = – 1.5 × 10^{-18} (J) **(1)**
level C = (–) 1.0 × 10^{-18} (J) **(1)**

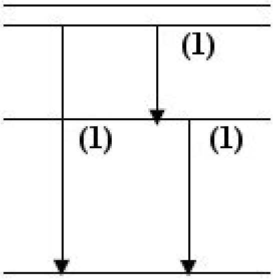
5

[8]

13 (a) ionisation energy = 13.6eV **(1)**

1

(b) (i)



(ii) energy in Joules = 1.90 **(1)** × 1.6 × 10^{-19} = 3.04 × 10^{-19} (J) **(1)**
(use of $E = hc/\lambda$)

$3.04 \times 10^{-19} = 6.63 \times 10^{-34} \times 3 \times 10^{8}/\lambda$ **(1)**
(working/equation must be shown)

$\lambda = 6.54 \times 10^{-7}$ m **(1)(1)** (2 or 3 sf for second mark)
(accept 0.65 which gives an answer of $\lambda = 1.91 \times 10^{-6}$ m)

8

[9]

14 (a) (i) an electron/atom is at a higher level than the ground state **(1)**

or electron jumped/moved up to another/higher level

1

(ii) electrons (or electric current) flow through the tube **(1)**

and collide with orbiting/atomic electrons or mercury atoms **(1)**

raising the electrons to a higher level (in the mercury atoms) **(1)**

3

(iii) photons emitted from mercury atoms are in the **ultra violet** (spectrum) **or** high energy photons **(1)**

these photons are absorbed by the powder **or** powder changes frequency/wavelength **(1)**

and the powder emits photons in the visible spectrum **(1)**

incident photons have a variety of different wavelengths **(1)**

max 3

(b) (i) (use of $E = hf$)

$-0.26 \times 10^{-18} - 0.59 \times 10^{-18}$ **(1)** $= 6.63 \times 10^{-34} \times f$ **(1)**

$f = 0.33 \times 10^{-18}/(6.63 \times 10^{-34}) = 5.0 \times 10^{14}$ (Hz) **(1)**

3

(ii) **one** arrow between n = 3 and n = 2 **(1)** in correct direction **(1)**

2

[12]

15 (a) (i) absorbs enough energy (from the incident) electron(by collision) OR incident electron loses energy (to orbital electron) ✓
exact energy / 10.1((eV) needed to make the transition / move up to level 2 ✓

For second mark must imply exact energy

2

(ii) *(use of $E_2 - E_1$) = hf*
$-3.41 - - 13.6 = 10.19$ ✓
energy of photon $= 10.19 \times 1.6 \times 10^{-19} = 1.63 \times 10^{-18}$ (J) ✓
$6.63 \times 10^{-34} \times f = 1.63 \times 10^{-18}$
$f = 2.46 \times 10^{15}$(Hz) ✓
(accept 2.5 but not 2.4)

CE from energy difference but not from energy conversion

3

(iii) $E_k = 1.7 \times 10^{-18} - 1.63 \times 10^{-18}$ ✓ $= 7.0 \times 10^{-20}$ J ✓

2

(iv) energy required is 12.09 eV / 1.9×10^{-18} ✓
energy of incident electron is only 10.63 eV / energy of electron less than this (1.7×10^{-18} J) ✓

State and explain must have consistent units i.e. eV or J

2

(b) (i) Electrons return to lower levels by different routes / cascade / not straight to ground state ✓

1

(ii) 3 ✓
n=3 to n=1 or n=3 to n=2 and n=2 to n=1 ✓

no CE from first mark

2

[12]

16 (a) an electron is removed from the atom **(1)**

(b) 2.18×10^{-18}(J) **(1)**

(c) (single photon):electron loses energy [or falls] from level $n = 3$ to $n = 1$ and emits a single photon **(1)**

(two photons): electron falls from level $n = 3$ to $n = 2$, emitting a photon **(1)**
followed by a fall from level $n = 2$ to $n = 1$, emitting another photon **(1)**

The Quality of Written Communication marks are awarded for the quality of answers tothis question.

(f) level n = 5 to the ground state [or $E_5 \rightarrow E_1$] **(1)**

(e) (use of $hf = E_1 - E_5$ gives) $f = \dfrac{(-0.54 \times 10^{-18} - -2.18 \times 10^{-18})}{6.63 \times 10^{-34}}$ **(1)**

$= 2.47 \times 10^{15}$ Hz **(1)**

[8]

17 (a) (i) –0.66 to –0.72keV line marked as **B** downward arrow

B1

(ii) uses 7.06 (eV) (condone negative sign)

B1

attempts to multiply by 1.6×10^{-16} (condone incorrect power of 10) and to divide by 6.63×10^{-34}

B1

$1.7(0) \times 10^{18}$ (Hz) cao

B1

4

(b) (i) $\lambda = h/mv$ or $\lambda = h/p$ or correct substitution

C1

4.4(2) × 10^6 (m s^{-1}) [4.8(5) with *h* to 2 sf]

A1

(ii) same order of magnitude as atomic spacing

B1

produces wide **diffraction** angle/good **diffraction**

B1

4

[8]

18 (a) (i) ultraviolet / UV / UV light / ultra(-)violet ✓

1

(ii) <u>electron</u>(in ground state) has moved / in to higher (energy) level / shell / orbital / state OR up level / shell / orbital / state ✓

Ignore reference to photons

1

(iii) (free) electrons collide with orbital electrons / mercury electrons / electrons in atom ✓

transferring energy ✓

Ignore any reference to photons

2

(iv) (mercury) atoms have discrete / fixed / specific energy levels ✓

when electrons change levels they lose an exact / fixed / specific / discrete / set amount of energy OR photons emitted with exact / fixed / specific / discrete / set amount of energy ✓

(leading to photons of) fixed / particular / certain / discrete / specific / unique frequencies ✓

Each mark independent

Don't accept characteristic for 3rd mark

3

(b) (i) (*use of* $\lambda = c / f$)

$f = 3 \times 10^8 / (254 \times 10^{-9})$ ✓

$f = 1.18 \times 10^{15}$ (Hz) ✓

AE penalty if give answer to 1 sig fig

2

(ii) (*use of $E = hf$*)

$E = 6.63 \times 10^{-34} \times 1.18 \times 10^{15} = 7.82 \times 10^{-19}$J ✓

$E = 7.82 \times 10^{-19} / 1.6 \times 10^{-19}$ ✓ = 4.9 (4.875) eV

CE part (i)

Range 4.8 − 5.0 acceptable

2

(c) coating <u>absorbs</u> photons / uv light ✓

and re-emits (photons) of low(er) energy / long(er) wavelength / low(er) frequency ✓

Ignore any description of mechanism

2

[13]

19 (a) (i) electrons passing through tube collide with electrons in mercury atom ✓

Allow mercury atoms collide with each other

transferring energy / atom gains energy from a collision ✓

causing orbital electrons / electrons in mercury atom to move to higher energy level ✓

Atomic electrons move from ground state

3

(ii) (each) excited electron / atom relaxes to a lower (energy) level ✓

allow excited electron / atom de-excites / relaxes

Allow excited electron / atom relaxes to ground state

Condone moves for relaxes

emitting a photon of energy <u>equal</u> to the energy difference between the levels ✓

2

(b) coating absorb (uv) photons (causing excitation) / (uv)photons collide with electrons in the coating (causing excitation) / electrons in coating are excited

allow <u>atoms</u> in coating absorb (uv) photons (causing excitation)

Atomic <u>electrons</u> de-excite indirectly to previous lower level (and in doing so emit lower energy photons) ✓

Owtte (must convey smaller difference between energy levels in a transition) cascade

2

[7]

20 (a) (i) pd across resistor (= 3.0 – 2.2) = 0.8 (V) **(1)**

(use of $V = IR$ gives) $R = \left(= \frac{0.8}{0.035}\right)$ = 23 Ω **(1)** (22.9 Ω)

(ii) charge flow in 1 s = 0.035 (C) **(1)**

no. of electrons (in 1 s) $\left(\frac{0.035}{1.6 \times 10^{-19}}\right)$ = 2.2×10^{17} **(1)** (2.19×10^{17})

4

(b) (i) (use of $E = hf = \frac{hc}{\lambda}$ gives) $E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{635 \times 10^{-9}}$ **(1)**

$= 3.1(3) \times 10^{-19}$ J **(1)**

(ii) (use of $P = VI$ gives) P (= 2.2 × 0.035) = 0.077 (W)

[or use of $P = I^2R$ with $R \left(= \frac{2.2}{0.035}\right)$ = 63 (Ω)]

maximum no. of photons emitted per sec. = $\frac{0.077}{3.1 \times 10^{-19}}$

$= 2.5 \times 10^{17}$ **(1)** (2.48×10^{17})

(allow C.E. for value of E from (i) and value of P from (ii))

4

[8]

Examiner reports

3 Approximately two thirds of students spotted that a bigger energy jump was needed to produce a photon of UV, and therefore chose D. Distractors A (the smallest energy jump) and C (the next smallest) were chosen by a similar number of students who failed to make the link between energy and frequency perhaps.

6 Part (a) tested the ability of candidates to explain a sequence of events. This was quite difficult in itself and the answers indicated clearly which were the good candidates. The idea of electrons moving between allowed orbits was understood by the majority of candidates but very few linked this to the production or absorption of specific wavelengths.

Most candidates experienced difficulty with one or more sections of part (b) and a good range of marks was obtained. In part (i) the conversion from electron volts to joules was usually incorrect or else the ionisation energy was not recognised as being 5.2 eV. In part (ii) the expression $f = c / \lambda$ was usually given but often not evaluated. It was also common to see the approximate answer of 5.0×10^{14} Hz being given as the final answer to the calculation. Again, in part (iii) the approximate value of the frequency was used by many candidates even though they had calculated an accurate value in the previous section. Of the candidates who were penalised for incorrect use of significant figures, about 90% of them were penalised in this section. Part (iv) required a line to be drawn on the diagram representing the emission of a photon. More often than not the line did not show the correct direction. The final two parts performed better but a common answer to part (vi) was a transition from A to E rather than the correct transition from B to C.

7 Many students were able to distinguish between excitation and ionisation successfully and also to define the ground state. They clearly found the structured format of this question helpful. However, students were not so good at explaining the process of excitation of atoms by the absorption of photons. It was common to see muddled answers that confused the photoelectric effect with excitation. The term *work function* was often used incorrectly in candidate responses as was threshold frequency. A significant minority focused on the photon released after excitation rather than the incident photon.

The calculation in part (c) was generally done well and most students gave answers to the correct number of significant figures. A common error by some students was to fail to convert electron volts to joules, this mistake limited them to a maximum of two marks.

8 Parts (a) and (b) of this question showed errors at different levels of ability. The slightly better candidates used the correct equations but often used the speed of light in the de Broglie relationship. The very weak candidates did not know when to apply $\lambda = \frac{h}{mv}$ or $\lambda = \frac{hc}{E}$. In other cases, the wrong energy was used to calculate the wavelength of a photon and it was not uncommon to see the electron energies at levels D and B being added together.

Part (a) (i) in particular showed a variety of errors. Multiplying, rather than dividing by the electron charge was the obvious error. Some of the better candidates used the electron speed to calculate the kinetic energy, arriving at the energy in joules which had already been given in the question, and then failing to convert this to eV. About 15% of the candidates incurred a significant figure error on this question by quoting an answer to five significant figures.

9 Many candidates scored full marks in part (a), although some lost a mark as a result of not converting d from mm into m and also giving 4.87×10^{-4} m as the wavelength. In part (ii), a significant number of candidates failed to convert correctly from joules into eV, often multiplying rather than dividing by 1.6×10^{-19}.

In part (b) (i), most candidates knew that the required transition occurred between energy levels A and C, but many indicated that the transition was either upwards or in both directions. Again, most candidates were able to show that the mean kinetic energy in part (ii) was 0.65 eV. In part (iii), only a small number of candidates realised that excitation of the gas atoms is due to collisions between the atoms, and that the spread of speeds of the gas atoms at 5000 K resulted in collisions which caused electrons in the atoms to move to the higher energy levels, including C. Some did realise that a 2.6 eV photon was emitted when an electron transition occurred from C to B. Sadly, the only credit gained in part (iii) by most candidates was for stating that a photon was emitted when de-excitation of a gas atom occurred. Some candidates thought that excitation in a heated gas is due to atoms absorbing photons rather than collisions between gas atoms.

10 (a) This was generally known well.

(b) (i) This was done well by the majority of the candidates although setting out of the working left something to be desired in many instances.

(ii) This part was usually correct but some omitted a unit.

(iii) Correct calculation of the circumference was essential to this part. A small but significant number of candidates did this incorrectly or compared the wavelength with the radius or diameter and therefore gained no credit.

(c) (i) This was usually correct. A few ignored the factor of 10^{19} or gave no unit.

(ii) This was also generally successfully completed.

(iii) The most common error was use of an incorrect energy difference. A small minority used $\lambda = \frac{h}{mv}$

11 Many were successful in obtaining the energy of the emitted photon and / or were able to convert 3.4 eV to J. Calculating the energy of the initial energy level proved more of a problem and there were many answers with the correct numerical value but no negative sign or answers where candidates calculated the energy level the electron would have to move into rather than from.

12 The description of how an excitation spectrum was produced was generally done well in part (a), but many candidates omitted the fact that energy had to be provided by some means to start the process.

In part (b) (i), candidates who were aware of the equation $E = hc/\lambda$ completed the calculations correctly, but there were a few significant figure errors and several candidates had trouble with powers of 10. The determination of the energy levels B and C in part (b) (ii) caused considerable difficulty, with only a minority of candidates obtaining the correct answers. The connection between the photon energies and the energy levels was not obvious to most candidates.

13 Correct responses for part (a) were common, although a significant minority of candidates did give the answer 12.75 eV which is the energy change from level one to level four.

The other parts of the question were answered well by the majority of candidates, with the only common errors occurring in the transition diagram, where often too many arrows were drawn or the arrows were shown in the wrong direction or there was no arrow at all. The calculation in part (b) (ii) was approached with confidence by many candidates and most appreciated that they were required to limit the number of significant figures in their answers.

14 Part (a) proved to be quite discriminating and less able candidates found it hard to explain the process by which mercury atoms become excited in a fluorescent tube. There was also evidence to suggest that some candidates think that excitation only occurs due to the absorption of photons and seemed unaware that it can also happen by electron collision. Most candidates seemed to appreciate that the mercury atoms emitted photons that were in the ultraviolet part of the spectrum and that the coating changed the frequency of these although there was a tendency to describe these photons as photons of light or coloured light rather than visible light.

Part (b) was answered well and the only common error was a failure to appreciate that the energy levels were in Joules and that the value adjacent to each level needed to be multiplied by 10^{-18}. A minority of candidates either emitted this factor or assumed that the energies were in electron volts and multiplied them by 1.6×10^{-19}.

15 This question required candidates to be familiar with discrete energy levels and excitation by electron collision. This is a topic which has caused problems in the past and it is clear that the ideas involved continue to trouble candidates.

In part (a) they were required to explain the process of excitation and less than 20% of candidates were awarded full marks for their answers. Many were able to explain the energy transfer that took place between the electrons but very few were able to explain convincingly that an exact amount of energy had to be transferred. It was also quite common to see answers referring to excitation due to photon absorption rather than electron collision. In part (a) (ii) candidates were required to calculate the frequency of the photon emitted when an electron drops to the ground state. This was generally done well although nearly a third of candidates failed to convert the energy in electron volts to joules and were therefore limited to one mark. The remaining parts of (a) were concerned with the energy of the incident electron. This question proved to be quite discriminating and only the stronger candidates managed to score full marks.

Part (b) also turned out to be very discriminating and only about half of candidates were able to explain why hydrogen atoms, whose electrons had been excited to level 3, were able to emit photons of three different frequencies.

16 Most candidates were aware of the answer to part (a) but failed to gain the mark by not stating explicitly that the electron was removed from the atom. Answers such as, ‘the atom goes to level $n = \infty$ ‘ were common. In part (b) the energy required to ionise the atom was often quoted as a negative quantity.

Part (c) tested candidates’ communication skills. Most candidates used much of the available space to describe the process of excitation but many were not clear as to how the two photons were produced. It was common to read statements such as ‘If the energy drop is very large two photons, not one, are produced’ or ‘Sometimes the single photon is replaced by two, each sharing the energy equally’

The transition between energy states in part (d) was often given the wrong way round with an electron in the ground state moving to level $n = 5$. In part (e) the frequency of the emitted photon was calculated successfully by most candidates with the remaining candidates falling into two groups; those who failed to use the factor of 10^{-18} in the energy value and those who failed to use the equation $\Delta E = hf$.

17 In part (a) (i) a good number of candidates correctly identified the energy change **B**. A significant minority penalised themselves by marking the arrow upwards. Others were penalised for making the change on top of the change **A**.

Most candidates attempting part (a) (ii) identified the energy changes as being 7.06 keV correctly and many then went on to convert this energy into joules (some forgetting the factor of 1000). Of those that did not convert the energy into joules, many divided their answer by the Planck constant. A significant number of candidates interpreted this question as being an example of the photoelectric effect.

Although many candidates gained the correct answer to part (b) (i) using the de Broglie equation, a large proportion managed to juggle $c = f\lambda$ to obtain a speed of 3.00×10^8 m s^{-1}. It was also common for the less able candidates to simply write down both these equations to gain no credit.

Part (b) (ii) was not done well and many candidates either completely missed it out or else said no more than the wavelength was small. Few candidates recognised that for effective diffraction the atomic spacing in the crystal needs to be of the same order of magnitude as the de Broglie wavelength of the incident particles.

18 Candidates often have problems when they are required to give extended written answers explaining aspects of quantum phenomena. This question on the fluorescent tube certainly provides evidence to support this.

While the calculations in part (b) were well done with full marks being obtained by a high proportion of candidates, this was not the case with the qualitative questions that made up parts (a) and (c). Candidates were generally able to explain the process of excitation and to apply this to the fluorescent tube. They were less confident however, when explaining why the mercury atom releases photons of characteristic frequencies. This question was often answered in general terms which explained why atoms release photons but did not explain why the frequencies of these photons where characteristic to atoms of particular elements such as mercury.

In part (c) about half the candidates realised that the coating absorbs the ultra violet photons but very few stated that the photons emitted by the coating were of lower frequency and just repeated the stem by stating that the coating emitted visible light.

19 Part (a)(i) was done well with almost 60 % of students achieving full marks. Many answers seen were of a good standard with students choosing their words carefully to effectively communicate the positions of the relevant electrons and each stage in the process. Students who fared less well simply stated the mercury atom became excited without detailing how this affected electrons within the atom. Other students were unaware of the process that led to the energy transfer with lots of students stating that it was due to absorption of a photon rather than an electron-electron collision. Part (a)(iii) was only completed to the desired standard by the most able of the students. Weaker responses stated that the energy emitted was lower in relaxation even though quite often the same energy level transition was quoted (ground to excited to ground). Higher achieving students communicated the idea that the transitions in relaxation were between closer lying energy levels resulting in a lower frequency photon being emitted.

20 Part (a) proved to be very accessible and many candidates scored full marks. Most candidates calculated the resistor pd as 0.8 V and then calculated the resistance, as expected. Other candidates however, calculated the total circuit resistance, then the diode resistance and obtained the required resistance by subtraction. In this particular problem some candidates used an incorrect pd and were not awarded any credit. Many clear and correct answers were seen in part (ii).

The energy of the photon was calculated correctly in part (b) by many candidates, but some failed to score because the wavelength was taken as 1 / f or because the energy was taken to be ½QV. The general principle behind the question in part (ii) was understood by most candidates and many correct answers were seen. A small minority of candidates however, calculated and used the power supplied to the resistor and not the diode.