LONDON SCIENCE COLLEGE

MARK SCHEME

PHYSICS

AS-Level

QUANTUM PHYSICS
TEST 1

Mark schemes

1

(a) energy of photon is constant / fixed OR energy given to electron is fixed ✓
energy required for electron to <u>leave / escape / emit</u> from the <u>surface / metal</u>
OR electron has to overcome work function ✓
maximum kinetic energy is the energy of photon minus the work function ✓
deeper electrons require energy to get to the surface OR have less E_k than surface electrons ✓

mention of energy levels means can only score first mark
photoelectric equation alternative for third mark if φ and hf defined

3 max

(b) (i) (*use of E = hf*)
energy of photon = $6.63 \times 10^{-34} \times 3.0 \times 10^{15}$ ✓ = 1.989×10^{-18} (J)
work function = $hf - E_k = 1.989 \times 10^{-18} - 1.7 \times 10^{-18} = 2.89 \times 10^{-19}$ ✓
work function = $2.89 \times 10^{-19} / 1.6 \times 10^{-19}$ ✓ = (1.8 eV)

hf gets first mark even if in wrong equation

3

(ii) work function = hf_0
$f_0 = 1.8 \times 1.6 \times 10^{-19} / 6.63 \times 10^{-34}$ ✓ = 4.3×10^{14} ✓ (Hz) ✓ (2 sig figs)

2 sig . fig stand alone mark
Accept 4.4×10^{14}

3

(c) (i) decrease the energy of(incident) <u>photons</u> ✓
decrease the <u>maximum</u> kinetic energy of electrons ✓
OR
decrease the energy of(incident) <u>photons</u> ✓
hence fewer deeper electrons escape ✓
OR
below <u>threshold frequency</u> ✓
no electrons emitted ✓
OR
as energy of each <u>photon</u> decreases but intensity is constant (there are more photons / sec) ✓
number of emitted electrons(/sec) must increase ✓

for <u>last two</u> alternatives must get first mark before can qualify for second mark

2

(ii) increase in photons cause increase in (emitted) electrons ✓
<u>double number</u> of electrons / photons OR reference to rate /per second ✓

if refer to energy levels / atoms can only award first mark

2

[13]

2 (a) Minimum energy to remove an electron

B1

from a (metal) surface

B1

2

(b) Converts 2.28 (e V) to 3.6×10^{-19} (J) / $2.28 \times 1.6 \times 10^{-19}$

C1

Condone minus sign here on energy or charge

Use of $hf = \varphi_0$

e.g. f = 2.28 / h (will need to see subject)

or $2.28 = 6.6(3) \times 10^{-34} \times f$ or $f =$

$2.28 / 6.6(3) \times 10^{-34}$ (will need to see subject)

Makes f subject or substitutes correctly for h and φ_0

C1

allow equivalent substitution into $hf = \varphi_0 + KE_{max}$ where $KE = 0$

Penalise minus sign on answer

(f =) $5.5(0) \times 10^{14}$ (Hz) cao

A1

3

[5]

3 (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) $Ek = 1.7 \times 10^{-18} - 1.63 \times 10^{-18}$ ✓ $= 7.0 \times 10^{-20}$ 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]

4 (a) (i) minimum energy required ✓

to remove electron from metal (surface) OR cadmium OR the material ✓

2

(ii) photons have energy dependent on frequency OR energy of photons constant ✓

one to one interaction between photon and electron ✓

Max KE = photon energy – work function in words or symbols ✓

more energy required to remove deeper electrons ✓

4

(iii) *(use of $hf = Ø + E_{k(max)}$)*

6.63 × 10^{-34} × f = 4.07 × 1.60 × 10^{-19} ✓ + 3.51 × 10^{-20} ✓

f = 1.04 × 10^{15} (Hz) OR 1.03 × 10^{15} (Hz) ✓ ✓(3 sig figs)

4

(b) theory makes predictions tested ✓ by repeatable/checked by other scientists/peer reviewed (experiments) OR new evidence that is repeatable/ checked by other scientists/peer reviewed✓

2

[12]

5 (a) passed them between charged plates / near charged object

or

use magnetic field

M1

correct deviation

or

circular path in direction indicating negative charge

A1

2

(b) diffraction

B1

electron is behaving as a wave

B1

2

(c) (i) $p = h/\lambda$ or **substitution of wavelength** into $\lambda = h/p$ *or* $\lambda = h/mv$

C1

2.76 or 2.8×10^{-19}

A1

kg m s^{-1} / N s / J s m^{-1} / J Hz^{-1} m^{-1}

B1

3

(ii) $E_K = p^2/2m$ or quotes p = mv **and** $E_k = ½ mv^2$
(symbols or numbers)

C1

4.1 or 4.2×10^{-8} (J)

A1

2

[9]

6 (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]

7 **C**

[1]

8 **D**

[1]

9 **D**

[1]

10 **C**

[1]

Examiner reports

1 This question was concerned with aspects of the photoelectric effect and this is a topic which has caused candidates real problems in previous series. This also proved to be the case in this exam.

Part (a) was not well answered and only about 5% of candidates scored full marks. In a significant proportion of scripts confusion with excitation was apparent and this restricted candidates to the first mark. Another common error was to assume that the photons had a range of energies and this led to a range of kinetic energies.

Part (b) was more quantitative in nature and as has been the case in the past, candidates performed better with a much higher proportion of candidates scoring full marks.

Part (c) was less well done and only the more able candidates were able to explain convincingly the effects of decreasing frequency and increasing intensity on electron emission. It was common to see answers which discussed threshold frequency rather than giving more general answers which covered the reduction in frequency above this limit.

2 (a) Performance of candidates in this question exemplifies performance across the paper as a whole.

The better candidates were able to produce a well-structured definition of the meaning of the work function. Others had a limited recall of the definition often omitting that it was the minimum energy or that it was a surface phenomenon.

(b) Over 10% of candidates did not attempt this question.

Of those who did make a start most achieved at least one mark. The most common error here was a failure to realise that 2.8eV had to be converted into joules. Correct answers were well-laid out with little to no spurious calculations seen.

3 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.

4 Students have found questions on the photoelectric effect quite challenging in previous series. In view of this it was pleasing to see more confident answers this time around. The explanation of work function and the calculation were well answered by a significant proportion of students. Explanations of the range of kinetic energies were less sound and as has been the case in the past there was frequent confusion between the photoelectric effect and excitation of electrons from discrete energy levels. The idea of validated evidence which was required in part (b), seems now to be well understood.

5 Strictly correct answers to part (a) were rare but credit was given to answers involving charged objects rather than parallel plates. Those who chose to use magnets, almost universally mentioned positive and negative poles of magnets! This was penalised.

Although there were some good answers to part (b) referring to the diffraction pattern and top the wave–particle duality, some interpreted the diagram as representing the energy levels in an atom.

In part (c) (i), the correct equation was generally used but students often did not use the correct substitution for wavelength. The unit for momentum was often correct. A disappointing number chose to give a version of the unit derived from the equation instead of an appropriate, remembered unit. A significant minority of students did not attempt (c) (ii). Most had no idea of how to find the kinetic energy from the momentum.

6 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.

7 Most students (67.8%) were able to relate this gradient to the hc.

8 Most students (64.8%) were able to select the correct answer, with distractor A being the most common wrong answer. These students did not take into account that the visible photon has a smaller energy than the ultraviolet photon.

9 Students were less confident with this question, with less than 38.8% selecting the correct answer. B and C were often selected as the answer, with students demonstrating limited ability to re-arrange the de Broglie equation in the required manner.

10 This question had a very high success rate with 84.2% of students able to recall the physical properties exhibited in the photoelectric effect and electron diffraction.