OXFORD
INTERNATIONAL
AQA EXAMINATIONS

INTERNATIONAL AS PHYSICS

(PH02)

Unit 2: Electricity, waves and particles

Example responses with commentary

For teaching from September 2016 onwards
For AS exams in May/June 2018 onwards

This guide includes some examples of student responses to a selection of questions from the summer 2018 PH02 unit.

The question parts are reproduced, along with the final mark scheme, student responses and a commentary from the Lead Examiner on each of the students' answers.

QUESTION

02

0 2 . 1 The work function of copper is 4.65 eV.

Explain the meaning of the term work function.

[1 mark]

____

____

____

0 2 . 2 Determine the threshold frequency for copper.

[3 marks]

0 2 . 3 Electromagnetic radiation of frequency 850 THz is incident on a sheet of clean copper.

Explain whether photoelectrons will be emitted from the surface of the copper.

[2 marks]

MARK SCHEME

Question	Marking guidance	Mark	Comments
02.1	<u>minimum</u> energy to remove an electron from the <u>surface</u> of a copper/metal ✓	1	
02.2	$4.65 \times 1.60 \times 10^{-19} = 7.44 \times 10^{-19}$ (J) ✓ Use of $f = \frac{\Phi}{h} \left(\frac{7.44 \times 10^{-19}}{6.63 \times 10^{-34}}\right)$ ✓ 1.12×10^{15} (Hz) ✓	3	Allow 2nd mark only for failure to convert work function into joule.
02.3	850×10^{12} Hz **OR** photon energy = 3.5 eV seen ✓ no photoelectrons emitted because *f* below threshold frequency **OR** no photoelectrons emitted because photon energy below ϕ ✓	2	Power of ten must be seen; do not allow SI prefix. Must give a reason. Comparison may be in joule. Allow valid conclusion based on an incorrect conversion of THz or an ecf from their 2.2

STUDENT A

0 2 . 1 The work function of copper is 4.65 eV.

Explain the meaning of the term work function.

[1 mark]

Minimum energy needed to liberate an electron or ~~to remove~~ it from it's surface.

0 2 . 2 Determine the threshold frequency for copper.

[3 marks]

$K_{E max} = hf - \phi$

$0 = hf - \phi$

$\phi = hf$

$4.65 \times 1.6 \times 10^{-19} = 6.63 \times 10^{-34} f$

$f =$

threshold frequency = 1.12×10^{15} Hz

0 2 . 3 Electromagnetic radiation of frequency 850 THz is incident on a sheet of clean copper.

Explain whether photoelectrons will be emitted from the surface of the copper.

[2 marks]

$850 \times 10^{12} = 8.5 \times 10^{14}$ Hz

No, they won't be emitted as the frequency ~~is~~ required to emit electrons, threshold frequency, is 1.12×10^{15} while 850 THz is lower so not enough energy

EXAMINER COMMENTARY

This is an accurate and convincing set of solutions. The explanation in 2.1 is clear and makes the clear point that the work function represents a minimum energy to remove the electron. The use of the word "surface" is also important in this explanation. Too often students will write about the "removal of an electron" leaving the examiner in doubt as to whether ionisation is implied in the answer.

Although the student does not use the normal symbols in the photoelectric equation in 2.2, the meaning and usage is clear and the conversion to joule from electronvolt is reasonably clear too.

In 2.3 there is some confusion as the threshold frequency lacks its unit. Nevertheless, there is a clear chain of argument together with work to show the meaning of GHz so both marks are awarded.

6 marks awarded.

STUDENT B

0 2 . 1 The work function of copper is 4.65 eV.

Explain the meaning of the term work function.

[1 mark]

work function ~~the~~ is the minimum energy needed ~~to~~ for an electron to escape from metal surface.

0 2 . 2 Determine the threshold frequency for copper.

[3 marks]

$$f_0 = \frac{\varphi}{h} = \frac{4.65 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = 1.12 \times 10^{15}\ Hz$$

threshold frequency = 1.12×10^{15} Hz

0 2 . 3 Electromagnetic radiation of frequency 850 THz is incident on a sheet of clean copper.

Explain whether photoelectrons will be emitted from the surface of the copper.

[2 marks]

the photoelectrons will not be emitted because the frequency of electromagnetic radiation is smaller than threshold frequency.

EXAMINER COMMENTARY

2.1 and 2.2 gain full credit. The solution in 2.2 is however less convincing than that from student A. The symbols are undefined and there is no underlying explanation of the solution. This is a "determine" question and the expectation for the answer for a question with this command verb is that a full explanation should be given.
The answer to 2.3 is not supported by statements of the frequencies in question, in particular with respect to the conversion of the radiation frequency to standard form. No credit is awarded given this important omission.

4 marks awarded.

QUESTION

03

0	3

A 0.20 kg mass suspended from a vertical spring makes 10 oscillations in a time of 5.1 s.

Calculate the spring constant.

[3 marks]

MARK SCHEME

Question	Marking guidance	Mark	Comments
03	T = 0.51 (s) ✓ Use $T = 2\pi\sqrt{\frac{m}{k}}$ in either substitution or re-arrangement ✓ 30 (N m^{-1}) ✓	3	Condone use of 5.1 for T for 2nd and 3rd mark 2 marks for 0.30 (N m^{-1})

STUDENT A

0 3 A 0.20 kg mass suspended from a vertical spring makes 10 oscillations in a time of 5.1 s.

Calculate the spring constant. $5.1 \div 10 = 0.51\,s.$

[3 marks]

$T = 2\pi\sqrt{\frac{m}{k}}$

$0.51 = 2\pi\sqrt{\frac{0.2}{k}}$

$1.02\pi = \sqrt{\frac{0.2}{k}}$

$1.0404\pi^2 = \frac{0.2}{k}$

$k = 0.019\ N m^{-1}$

spring constant = 0.019 $N\,m^{-1}$

EXAMINER COMMENTARY

The solution begins well, but in an unexplained way, with a calculation of the time period of the oscillation. Between lines 3 and 4 there is an error in the manipulation of the equation with the factor of 2 being lost and π appearing incorrectly. This leads to an incorrect answer and credit only for the first mark.

1 mark awarded.

STUDENT B

Do not write outside the box

0 3 A 0.20 kg mass suspended from a vertical spring makes 10 oscillations in a time of 5.1 s.

Calculate the spring constant.

[3 marks]

$\therefore T = 2\pi\sqrt{\frac{m}{k}}$

$\therefore \frac{5.1}{10} = 2\pi\sqrt{\frac{0.20}{k}}$

$\therefore k = 30.4\ Nm^{-1}$

spring constant = 30.4 $N\,m^{-1}$

3

EXAMINER COMMENTARY

The re-arrangement of the equation is not completely set out, but the answer is correct and therefore the manipulation must have been correct. Full credit is given.

3 marks awarded.

QUESTION

05

0	5

A stretched string of mass 3.3×10^{-3} kg and length 0.75 m vibrates at the first harmonic when the tension in the string is 20 N.

Calculate the frequency of the first harmonic.

[3 marks]

MARK SCHEME

Question	Marking guidance	Mark	Comments
05	Use of $\mu = \frac{m}{l}$ $(\frac{3.3\times10^{-3}}{0.75}$ **OR** 4.4×10^{-3} kg m^{-1} seen) ✓ Substitution into $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ (eg $\frac{1}{2\times0.75}\sqrt{\frac{20}{4.4\times10^{-3}}}$) ✓ f = 45 (Hz) ✓	3	 Allow use of m (3.3×10^{-3}) for μ for this mark Allow 2 marks for 52 Hz (ie use of m)

STUDENT A

0 5 A stretched string of mass 3.3×10^{-3} kg and length 0.75 m vibrates at the first harmonic when the tension in the string is 20 N.

Calculate the frequency of the first harmonic.

[3 marks]

$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

$= \frac{1}{2 \times 0.75}\sqrt{\frac{20}{3.3 \times 10^{-3}}}$

$= 51.9$ Hz

frequency = 51.9 Hz

EXAMINER COMMENTARY

This student has failed to appreciate that the symbol μ in the equation for frequency represents the mass per unit length of the string, not the mass itself. The final two marks in the scheme are awarded as an error carried forward but the first mark is lost.

2 marks awarded.

STUDENT B

0 5 A stretched string of mass 3.3×10^{-3} kg and length 0.75 m vibrates at the first harmonic when the tension in the string is 20 N.

Calculate the frequency of the first harmonic.

[3 marks]

$F = ma$

$20 = (3.3 \times 10^{-3})(a)$

$a = \frac{20}{3.3 \times 10^{-3}} = \frac{200000}{33}$

$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

$f = \frac{1}{(2)(0.75)}\sqrt{\frac{20}{3.3 \times 10^{-3}}}$

$f = 16.412$

frequency = 16.4 Hz

EXAMINER COMMENTARY

Student B also fails to appreciate that $\mu = \frac{\text{string mass}}{\text{string length}}$ losing the first mark. This was an error that was common in the scripts and shows the need for students to be well versed in both the meaning of the symbols in equation and also the conceptual basis for them. This student has also invoked a form of Newton's second law but the way in which this has been incorporated into the solution is not clear. The final answer is wrong, losing the third mark from the scheme.

1 mark awarded.

QUESTION

06

0	6

Figure 3 shows a circuit used to determine the emf and internal resistance of a cell.

Figure 3

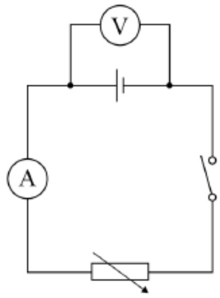
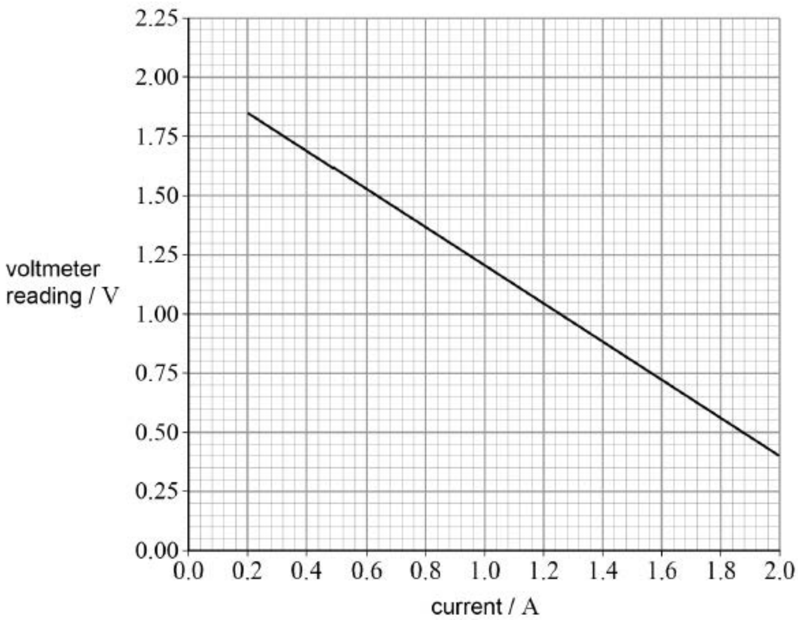


Figure 4 shows the variation of the voltmeter reading with current in the circuit as the variable resistor is adjusted.

Figure 4



0 6 . 1 The circuit contains an ideal voltmeter and an ideal ammeter.

State the resistance of an ideal voltmeter.

[1 mark]

0 6 . 2 Show that the internal resistance of the cell is approximately $0.8\ \Omega$.

[1 mark]

0 6 . 3 The variable resistor is adjusted until the current in the circuit is $2.10\ A$.

Calculate the resistance of the variable resistor.

[3 marks]

MARK SCHEME

Question	Marking guidance	Mark	Comments
06.1	infinite ✓	1	Condone "very large"
06.2	Evidence of using graph to get gradient **OR** use of intercept (2 V) and a data point eg (1, 1.2) ✓	1	Must be a correct pair of coordinates.
06.3	$E = 2.00$ (V) ✓ Substitution into $E = I(R + r)$ (eg candidate's $E = 2.1(R + 0.8)$) ✓ 0.15(2) (Ω) ✓ **OR** Total $R = 2.00/2.1 = 0.95$ ✓ $R = 0.95 – 0.8$ ✓ 0.15(2) (Ω) ✓	3	Alternative method: Deduce pd correctly (0.32 V) and substitute into $R = V/I = 0.32/2.1$ Allow reasonable range for data extraction Allow 1 max for any extrapolation done by extending the grid and line but reward a "mathematical" extrapolation such as using similar triangles.

STUDENT A

0 6 . 1 The circuit contains an ideal voltmeter and an ideal ammeter.

State the resistance of an ideal voltmeter.

[1 mark]

$R = \frac{V}{I}$ $\frac{1.85}{0.2} = 9.25\ \Omega$

0 6 . 2 Show that the internal resistance of the cell is approximately 0.8 Ω.

[1 mark]

$V = 1.375$

0 6 . 3 The variable resistor is adjusted until the current in the circuit is 2.10 A.

Calculate the resistance of the variable resistor.

[3 marks]

$V = 0.3$

$I = 2.1$ $R = \frac{V}{I}$ $R = \frac{0.3}{2.1} = \frac{1}{7} \approx 0.143$

3 s.f.

EXAMINER COMMENTARY

Student A carries out an unnecessary calculation to determine the resistance of the voltmeter not understanding the implication of the word "ideal" in the question. The physics of the calculation is, of course, incorrect. No credit can be given.
Question 6.2 shows a mis-reading. The valid of *V* quoted is the read-off for a current of 0.80 A. No credit.
In 6.3 the graph shows a common error where the student has extended the line beyond the limits of the grid. This is not a valid piece of manipulation: data from a graph should be restricted that obtained from the grid area. There is partial credit for the use of $R = \frac{V}{I}$ in this question. Note that it is usually necessary for the equation from the Formulae sheet to be manipulated or re-arranged for a mark to be awarded. A quotation direct from the sheet with no further working does not usually score.

1 mark awarded.

STUDENT B

0 6 . 1 The circuit contains an ideal voltmeter and an ideal ammeter.

State the resistance of an ideal voltmeter.

[1 mark]

Infinity

0 6 . 2 Show that the internal resistance of the cell is approximately $0.8\ \Omega$.

[1 mark]

$$\frac{0.40 - 1.85}{2.0 - 0.2} = -0.8056 \rightarrow 0.8056\,\Omega$$

0 6 . 3 The variable resistor is adjusted until the current in the circuit is 2.10 A.

Calculate the resistance of the variable resistor.

[3 marks]

$$\text{emf} = 2.00\ \text{V}$$

$$\varepsilon = I(R + r) \rightarrow \varepsilon = IR + Ir \rightarrow R = \frac{\varepsilon - Ir}{I}$$

$$R = \frac{2.00 - (2.10 \times 0.8056)}{2.10}$$

$$= 0.1468$$

resistance = 0.15 Ω

EXAMINER COMMENTARY

All parts of this question are reasonably, but not completely, answered. In 6.1 the word “infinity” is stark and students should be aiming for a minimum answer of “infinite resistance”. There is little explanation in 6.2. The final step “-0.8056 ⇨0.80556 Ω” is poorly expressed and there is no final statement to indicate that the obtained value for *r* is identical to the “show that” value.

6.3 is better with a statement of the equation in use and a final clear rounding to two significant figures at the end.

Nevertheless all answers are correct and no marks are lost.

5 marks awarded.

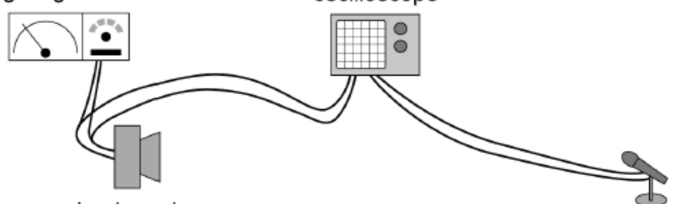
QUESTION

07.3 AND 07.4

0 7 A signal generator causes a loudspeaker to emit continuous sound waves of constant frequency f. A microphone placed $5.0\ \mathrm{m}$ away from the loudspeaker detects the sound waves. A dual-trace oscilloscope displays the output from the signal generator and the output from the microphone at the same time.

The speed of sound in air is $340\ \mathrm{m\ s^{-1}}$.

Figure 5



0 7 . 3 The oscilloscope shows a phase difference between the sound waves emitted by the loudspeaker and the sound waves arriving at the microphone.

Calculate in degrees the phase difference.

[1 mark]

0 7 . 4 The phase difference can be reduced to zero by increasing the frequency of the signal generator.

Determine the minimum increase required in the frequency of the signal generator to make the phase difference zero.

[4 marks]

MARK SCHEME

Question	Marking guidance	Mark	Comments
07.3	72 or 288 (degrees) ✓	1	
07.4	Recognition that 13 cycles are needed ✓ New $\lambda = 0.385$ (m) i.e. $\frac{5.0}{13}$ **OR** new $T = \frac{1.46\times10^{-2}}{13}$ ✓ New $f = 884$ (Hz) ✓ their new f - 870 (Hz) ✓	4	Allow for rounding errors Their new f must be greater than 870. Allow use of their **7.2**

STUDENT A

0 7 . 3 The oscilloscope shows a phase difference between the sound waves emitted by the loudspeaker and the sound waves arriving at the microphone.

Calculate in degrees the phase difference.

[1 mark]

12.8 : 5
1 : 0.39

1 L = 0.078 λ

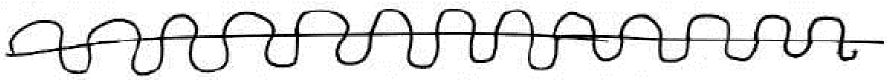
$\frac{64}{5}$ L = λ

phase difference = ~~[illegible]~~ 270° degrees

0 7 . 4 The phase difference can be reduced to zero by increasing the frequency of the signal generator.

Determine the minimum increase required in the frequency of the signal generator to make the phase difference zero.

[4 marks]



870 : ~~[illegible]~~ 12.8

x : 13

x = 883.59
= 883.6

Full wave will have 0 phase difference.

883.6 − 870 = 13.6

minimum increase in frequency = 13.6 Hz

EXAMINER COMMENTARY

The solution to 7.3 shows little understanding of the significance of 0.8 cycle. The presence of the figure 5 in the ratio is obscure and there is no further credit after this point.
Equally, the working in 7.4 is difficult to follow. The student is apparently following route 1 in the mark scheme (predicting the frequency for 13 cycles). However, the answer is correct and full credit is given.

4 marks awarded.

STUDENT B

0 7 . 3 The oscilloscope shows a phase difference between the sound waves emitted by the loudspeaker and the sound waves arriving at the microphone.

Calculate in degrees the phase difference.

[1 mark]

$0.8 \times 360 = 288°$

phase difference = 288 degrees

0 7 . 4 The phase difference can be reduced to zero by increasing the frequency of the signal generator.

Determine the minimum increase required in the frequency of the signal generator to make the phase difference zero.

[4 marks]

$\cancel{T = \frac{0.015}{13} = 1.154 \times 10^{-3}}$ 0.0147

$\cancel{f = \frac{1}{T} = 866.5}$

$T = \frac{0.0147}{13} = 1.131 \times 10^{-3}$

$f = \frac{1}{T} = \frac{1}{1.131 \times 10^{-3}} = 884.2\ Hz$

$884.2 - 871 = 13.2\ Hz$

minimum increase in frequency = 13.2 Hz

EXAMINER COMMENTARY

There is little explanation of the method but the answer is correct. (The student is evaluating the fraction of 360° represented by 0.80 of a cycle.)
In 7.4 the alternative method to that used by student A is seen. Once again, there is little explanation but the essential points required in the mark scheme are present.

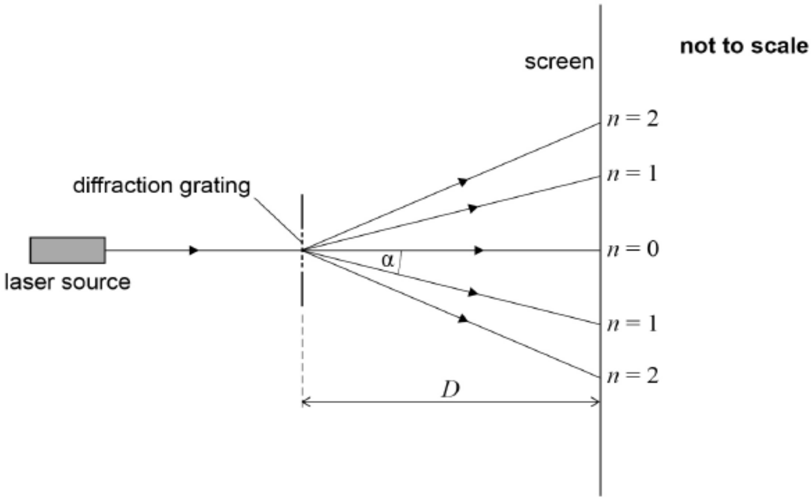
5 marks awarded.

QUESTION

08

0 8 A student wants to determine the wavelength of laser light using a diffraction grating. She sets up the experiment as shown in **Figure 6**.

Figure 6



The student observes five maxima of light on the screen. To determine the angle between each maximum and the zero-order maximum, she measures:

- the distance D between the screen and the diffraction grating
- the separation y of each maximum from the zero-order maximum.

Table 1 shows the results.

Table 1

n	D / m	y / m
1	2.000	0.878
2	2.000	2.704

0 8 . 1 **Figure 6** has an angle marked α.

Show that α is approximately $24°$

[1 mark]

0 8 . 2 The diffraction grating has 600 lines per millimetre.

Calculate the wavelength of the light.

[3 marks]

0 8 . 3 Explain how a second-order maximum occurs on the screen.

[3 marks]

MARK SCHEME

Question	Marking guidance	Mark	Comments
08.1	$\tan\theta = 0.878/2.000$ (= 23.7°) ✓	1	
08.2	$d = 1.67\times10^{-6}$ (m) ✓ Substitution into $\lambda = d \sin\theta$ **OR** $\lambda = \frac{\sin\theta}{N}$ ✓ 6.7×10^{-7} (m) **OR** 6.8×10^{-7} (m) ✓	3	Condone power of ten error in d for 1st and 2nd marks Accept other values if appropriate unit given (eg 670 nm)
08.3	light from different slits overlaps (because of diffraction) ✓ two wavelength path difference (from adjacent slits) ✓ (resulting in) zero phase difference (at screen) OWTTE ✓ constructive interference occurs✓	**max** 3	Allow appropriate marking points if clear on a diagram eg light diffracting from slits; 2 λ path difference

STUDENT A

0 8 . 1 **Figure 6** has an angle marked α.

Show that α is approximately 24°

[1 mark]

Overall angle = 72°

Splits to A 24 + 24 + 12 + 12

α = 24° (the bigger angle)

0 8 . 2 The diffraction grating has 600 lines per millimetre.

Calculate the wavelength of the light.

[3 marks]

$c = f\lambda$

$f = \frac{1}{T}$

$f = \frac{1}{600}$

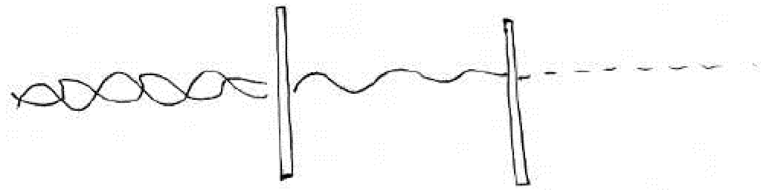
$3\times10^8 = \left(\frac{1}{600}\right)(\lambda)$

$\lambda = \frac{3\times10^8}{\left(\frac{1}{600}\right)} = 1.8\times10^{11}$

wavelength = 1.8×10^{11} m

0 8 . 3 Explain how a second-order maximum occurs on the screen.

[3 marks]



Some filters aren't enough to get rid or filter out some of the waves. So some waves are able to pass through the filter, which causes a second-order "maximum" on the screen. It is a maximum, so it's a bright fringe. Bright fringes occur when the peak of the waves are in phase. Or super conductivity waves formed.

EXAMINER COMMENTARY

In 8.1 there is no attempt at the required trigonometric solution. The solution to 8.2 involves the spurious use of $c=f\lambda$. A mark might have been available for a correct conversion of the number of grating lines per millimeter into a grating spacing but this was left with a power of ten error and in surd form. There appears to be confusion with polarisation ideas in 8.3 but there is some credit for the idea that a bright (maximum) fringe corresponds to the overlapping waves being in phase.

1 mark awarded.

STUDENT B

0 8 . 1 **Figure 6** has an angle marked α.

Show that α is approximately 24°

[1 mark]

~~$d\sin\theta = n\lambda$~~

$\tan\alpha = \frac{y}{D}$

$\therefore \alpha = \tan^{-1}\left(\frac{0.878}{2}\right) = 23.7°$

0 8 . 2 The diffraction grating has 600 lines per millimetre.

Calculate the wavelength of the light.

[3 marks]

$d = \frac{1\times10^{-3}}{600} = 1.667\times10^{-6}$

$d\sin\theta = n\lambda$

$\lambda = \frac{1.667\times10^{-6}\times\sin 24°}{1}$

$= 6.8\times10^{-7}$

0 8 . 3 Explain how a second-order maximum occurs on the screen.

[3 marks]

The waves ~~from gratin~~ diffraction occur after passing through the gap, and the waves constructive with each other with larger angle to ovelap on the screen.

EXAMINER COMMENTARY

The solutions for 8.1 and 8.2 are completely correct and explain the student's work well. The answer to 8.3 is however too general in its approach. The mention of "…a second-order maximum..." implies that specific reference must be made to this particular case. While it is true that diffraction occurs in the space between the grating and the screen, this is not material to the answer. The last part of the sentence dealing with the waves interfering is too vague for credit.

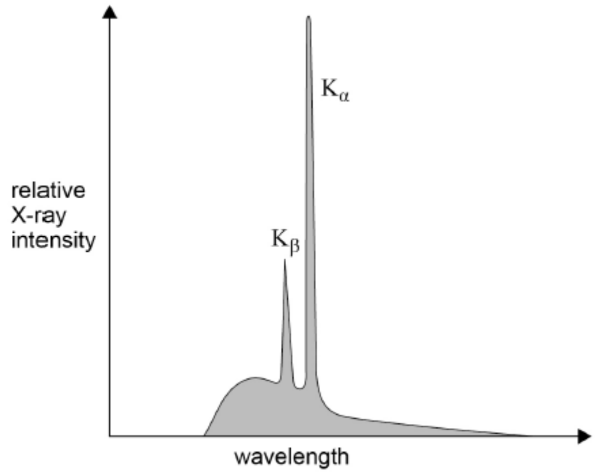
4 marks awarded.

QUESTION

09.1

0 9 **Figure 7** shows the spectrum from an X-ray tube. The two peaks, labelled K_α and K_β, correspond to the production of characteristic X-rays.

Figure 7



0 9 . 1 Explain how characteristic X-rays are produced in an X-ray tube.

[3 marks]

MARK SCHEME

Question	Marking guidance	Mark	Comments
09.1	Any three from Electrons (from beam) collide with metal target or anode✓ Idea of excitation followed by de-excitation OWTTE ✓ …involving the inner/K shell ✓ Photons emitted during de-excitation ✓ Photon energy = difference in energy levels ✓	max 3	Must be clear about which electrons are moving

STUDENT A

0 9 . 1 Explain how characteristic X-rays are produced in an X-ray tube.

[3 marks]

~~X-rays can be ionised and then the energy is emitted from the atom~~

The energy of photons is absorbed by the atom when the atom is excited and de-excited so that produce the ~~fx~~ characteristic frequency of X-rays. in an X-ray tube.

EXAMINER COMMENTARY

Students should always be guided by the mark allocation in questions of this type. Three independent points, well made, are required for full credit in this case. Five separate marking points are available. There is a mark given here with benefit of the doubt in the second marking point for the final 12 words of the answer. The doubt arises because the student begins by suggesting that the energy of *photons* is absorbed by the atom. It is, of course, the energy from incident high-energy electrons that is responsible for the generation of X-radiation.

1 mark awarded.

STUDENT B

0 9 . 1 Explain how characteristic X-rays are produced in an X-ray tube.

[3 marks]

Filament heats up the cathode.
Electrons strike the anode from the cathode therefore exciting the atoms in the anode.*
As the atoms de-excite, they return to ground state in quantum or in specific energy levels. This means that they emit X-ray ~~photons~~ photons of characteristic energies. during de-excitation.
* In the process one electron of the anode absorbs energy of one electron.

EXAMINER COMMENTARY

Student B provides a number of valid points: (1) collision of electrons with the metal target, (2) ideas of excitation and de-excitation, (3) emission of photons. These contribute to full credit for the answer.

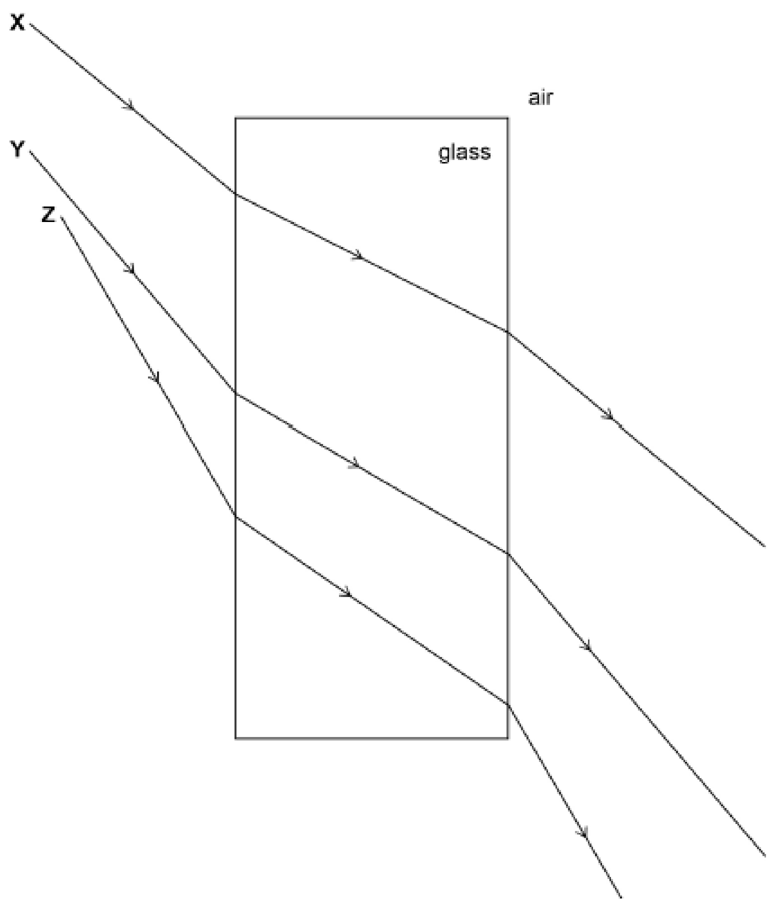
3 marks awarded.

QUESTION

10

1 0 Figure 9 shows the paths of three light rays **X**, **Y** and **Z** as they pass through a rectangular glass block.

Figure 9



1 0 . 1 Determine the refractive index of the glass for ray **X**.

Use a protractor to take suitable measurements from **Figure 9**.

[3 marks]

1 0 . 2 Assume that the percentage uncertainty in the sine of an angle is equal to the percentage uncertainty in the measurement of that angle.

Take the absolute uncertainty of measurement of all angles in this question to be ±1°

Calculate the absolute uncertainty in your answer to question **10.1**.

[3 marks]

1 0 . 3 State and explain which of the three rays is most likely to provide a value for refractive index with the smallest **percentage** uncertainty.

[2 marks]

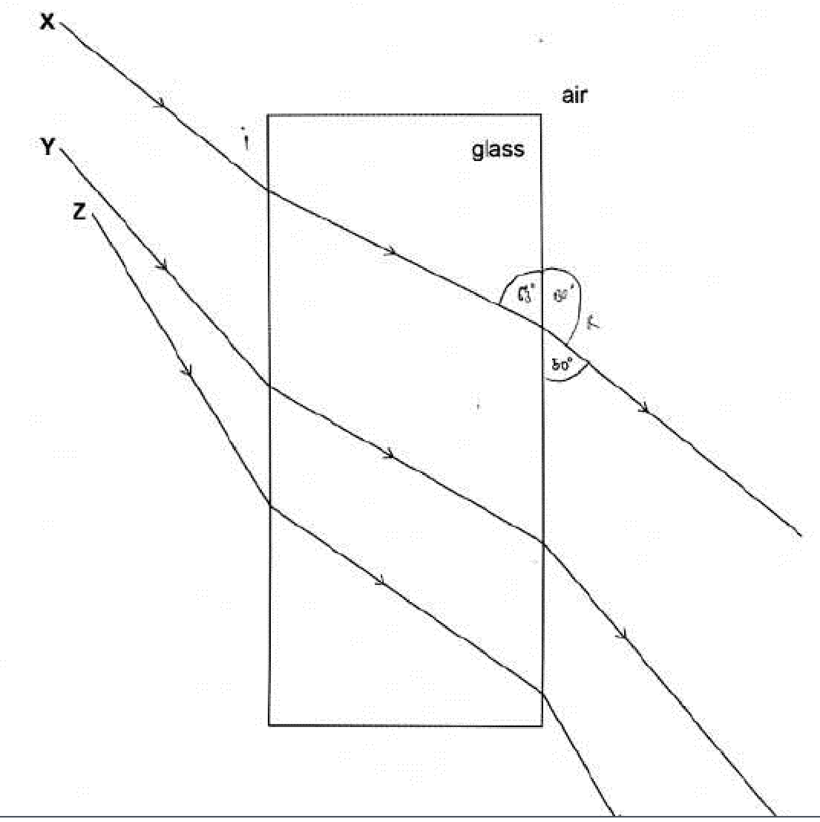
MARK SCHEME

Question	Marking guidance	Mark	Comments
10.1	angle of incidence = 40°±1° and angle of refraction = 27°±1° seen in calculation or on diagram for ray **X** ✓ Use of $\frac{\sin i}{\sin r}$ ✓ Refractive index from i = 40° and either r = 27° or 28° ✓	3	Accept 2 or 3 sf only Expect answers in the range 1.37 to 1.42
10.2	One value of percentage uncertainty calculated correctly ✓ Percentage uncertainties for $\sin i$ and $\sin r$ added ✓ Absolute uncertainty in the range 0.07 to 0.09 ✓	3	Allow fractional instead of percentage uncertainties No sf penalty Allow ECF from **10.1**
10.3	Ray **Z** because it has the largest angle of incidence/refraction ✓ Percentage uncertainty = $\frac{\text{absolute uncertainty}}{\text{angle of incidence}} \times 100$ ✓	2	Accept "percentage uncertainty is inversely proportional to angle" or a comparison of absolute uncertainty (±1) to angle.

STUDENT A

1 0 **Figure 9** shows the paths of three light rays **X**, **Y** and **Z** as they pass through a rectangular glass block.

Figure 9



10.1 Determine the refractive index of the glass for ray **X**.

Use a protractor to take suitable measurements from **Figure 9**.

[3 marks]

$i = \frac{1}{r}$ $\quad r = \cancel{4}$ $\quad \frac{1}{50} = 0.02$

$r = \frac{1}{1}$

$i = \frac{1}{\sin(63)} = 0.01587$

refractive index = 0.02

10.2 Assume that the percentage uncertainty in the sine of an angle is equal to the percentage uncertainty in the measurement of that angle.

Take the absolute uncertainty of measurement of all angles in this question to be ±1

Calculate the absolute uncertainty in your answer to question **10.1**.

[3 marl

$\sin 63 = 0.02$ $\quad \sin(0.02) + \sin(63) = 0.891$

$\sin(0.02) = 3.49 \times 10^{-4}$

absolute uncertainty = ± 0.891

10.3 State and explain which of the three rays is most likely to provide a value for refractive index with the smallest **percentage** uncertainty.

[2 marks]

Ray Z, it has the smallest angle out of all 3 rays. Because the lower the angle, the lower the product will be, so in the end it will have the smallest percentage uncertainty.

EXAMINER COMMENTARY

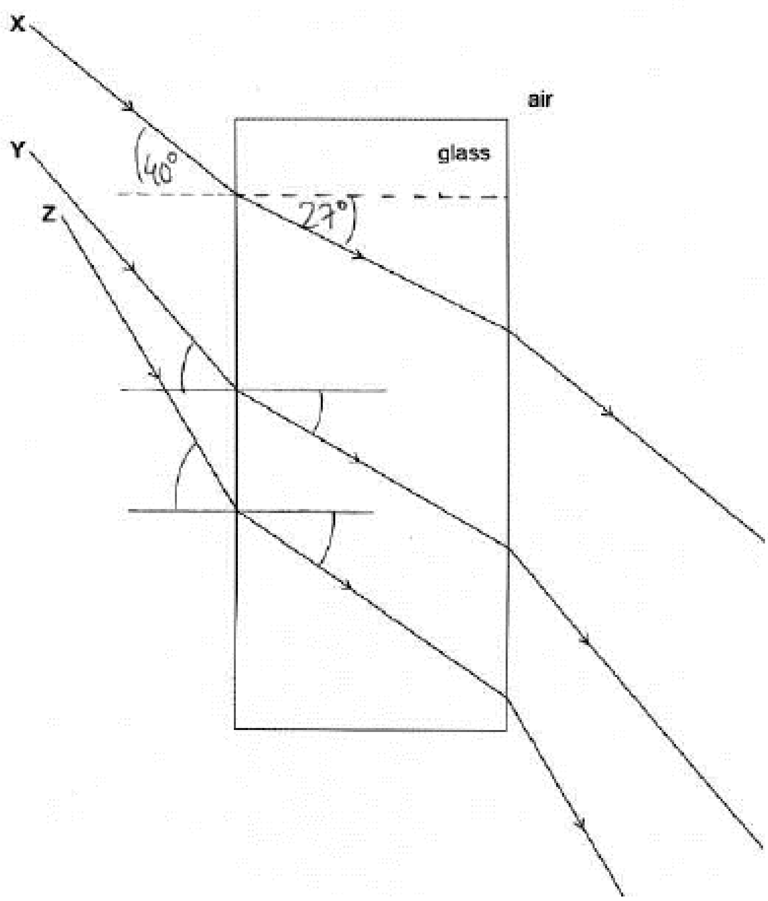
In Question 10.1 no credit can be given for the graph work. The working in the answer space contains a confusion with the equation linking the critical angle and refractive index. No marks are awarded here either.
The work in 10.2 is equally unclear. The first equation equates the sine of an angle to the refractive index and no further progress is made.
Although, in 10.3, the correct ray is identified, a correct, basic explanation is required. This is missing here and there is no detailed reference to the relationship between percentage uncertainty and absolute uncertainty.

0 marks awarded.

STUDENT B

1 0 **Figure 9** shows the paths of three light rays **X**, **Y** and **Z** as they pass through a rectangular glass block.

Figure 9



10.1 Determine the refractive index of the glass for ray **X**.

Use a protractor to take suitable measurements from **Figure 9**.

[3 marks]

$\cancel{80}\ \theta_i = 40°\quad \theta_r = 27°$

$n_1 = 1$

$n_1 \sin\theta_1 = n_2 \sin\theta_2 \rightarrow n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}$

$= \frac{\sin(40°)}{\sin(27°)}$

$= 1.415$

refractive index = 1.42

10.2 Assume that the percentage uncertainty in the sine of an angle is equal to the percentage uncertainty in the measurement of that angle.

Take the absolute uncertainty of measurement of all angles in this question to be ±1°

Calculate the absolute uncertainty in your answer to question **10.1**.

[3 marks]

$\delta n_2 = \delta \sin\theta_i + \delta \sin\theta_r$

$\delta \sin\theta_1 = \frac{1}{40} \times 100 = 2.5\%\quad \delta\sin\theta_r = \frac{1}{27} \times 100 = 3.7\%$

$\delta n_2 = 2.5\% + 3.7\% = 6.2\%$

absolute $\pm = 1.42 \times 6.2\% = \cancel{1.4820}\ 0.08804$

0.09

absolute uncertainty = ± ~~1.48088~~ 0.09

10.3 State and explain which of the three rays is most likely to provide a value for refractive index with the smallest **percentage** uncertainty.

[2 marks]

Z because it has the biggest angle of incidence and angle of refraction.

EXAMINER COMMENTARY

In 10.1 the measurements are within range and there is substitution into an appropriate equation leading to a correct calculation.
The working in 10.2 is also correct with a clear exposition of the method.
In 10.3, however, only the first marking point is scored as there is no detailed reference to the relevant link between percentage and absolute uncertainties.

7 marks awarded.

QUESTION

11.2 AND 11.3

1 1 A device uses the gravitational potential energy stored by a mass of 12.5 kg that is connected by a chain to a gear system. The mass is released from rest and falls through a height of 1.8 m.

The mass falls at a constant speed of 1.5 mm s^{-1} pulling the chain through the gear system. The gear system spins a generator that provides an electric light with a potential difference of 2.7 V and 80 mW of power.

1 1 . 2 Suggest **one** change to this device that would increase the maximum power available.

[1 mark]

1 1 . 3 Inefficiencies occur in both the gear system and the generator.
The efficiency of the gear system is 0.60

Calculate the efficiency of the generator when producing an output of 80 mW.

[2 marks]

MARK SCHEME

Question	Marking guidance	Mark	Comments
11.2	One from Greater mass✓ Increased speed of fall ✓	max 1	
11.3	Overall efficiency = $0.08 \div 0.18(4)$ **OR** Useful output power of gear system = $0.6 \times 0.18(4)$ ✓ 0.72 **OR** 0.73 **OR** 0.74 ✓	2	Condone efficiencies as percentages provided that "%" included

STUDENT A

11.2 Suggest **one** change to this device that would increase the maximum power available.
[1 mark]

Can make the ~~ke~~ falls through a height increase.

11.3 Inefficiencies occur in both the gear system and the generator.
The efficiency of the gear system is 0.60

Calculate the efficiency of the generator when producing an output of 80 mW.
[2 marks]

$$\text{efficiency} = \frac{\text{available power}}{\text{total power}}$$

$$= \frac{0.184}{80 \times 10^{-3}}$$

$$= 2.3$$

efficiency =

EXAMINER COMMENTARY

In 11.2 there are two ways in which the maximum power output can be increased; increasing the falling mass or increasing the speed of its fall. Changing the fall distance alone will change the *amount* of gravitation potential energy available but not the *rate* at which it can be delivered. This was a fundamental point missed by many students.
In 11.3 the answer is written poorly (the quoted result is 2.3). The student has ignored the efficiency of the gear train (one error) and has misunderstood what is meant by efficiency (second error). Accordingly, no marks are given for this part. The fact that the answer is not written on the answer line is not material to the mark. However, when a transcription error occurs between the final computation and the answer appearing on the answer line, the examiner will use the value on the answer line to arrive at the overall mark.

0 marks awarded.

STUDENT B

11.2 Suggest **one** change to this device that would increase the maximum power available.
[1 mark]

Increase the mass of object to increase the ~~gravi~~ gravitational potential energy.

11.3 Inefficiencies occur in both the gear system and the generator.
The efficiency of the gear system is 0.60

Calculate the efficiency of the generator when producing an output of 80 mW.
[2 marks]

~~0.184 × 0.6~~ =

$0.184 \times 0.6 = 0.1104$ W

$$\frac{80 \times 10^{-3}}{0.1104} = 0.72$$

efficiency = 0.72

EXAMINER COMMENTARY

The answer to 11.2 is correct but could have gone on to make the point that the mass increase leads to an increase in the *rate* at which energy is delivered.

Question 11.3 is correct but an explanation is lacking. Ideally both the first and second lines in the answer would have merited a word equation to outline physics involved. The lack of such explanation can lead to a loss of consequential marks when the examiner cannot understand the origin of the values used.

3 marks awarded.

FURTHER GUIDANCE AND CONTACTS

You can contact the subject team directly at science@oxfordaqaexams.org.uk

Please note: We aim to respond to all email enquiries within two working days.

Our UK office hours are Monday to Friday, 8am – 5pm local time.

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