OCR A Level Physics A (H556) Physics B (H557)
PAG 6: Investigating quantum effects
Practice Exam Questions and Mark Scheme

1. A narrow beam of unpolarised light is incident at the boundary between air and glass.

Fig. 18 shows the incident ray, the reflected ray and the refracted ray at the air-glass boundary.

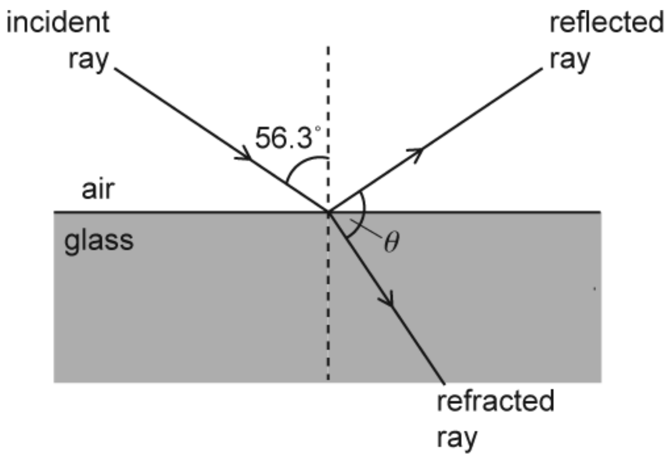

Fig. 18 (not to scale)

Describe how you can demonstrate in the laboratory that reflected light is plane polarised.

-- **[2]**

2. * Students are given a glass block and a ray box to determine the refractive index of glass. The students measure the angle of incidence *i* and the angle of refraction *r*. The table shows the results collected by the students.

i / ° ± 0.5°	10	20	30	40	50	60	70	80
r / ° ± 0.5°	6	13	20	25	31	35	39	41

The refractive index of air is 1.00.

Describe, with the help of a labelled diagram, how the students may have conducted the experiments in the laboratory.

Discuss how you could use the data from the table to graphically determine a value for the refractive index of glass.

[6]

3. A researcher is investigating the work function of metals using the photoelectric effect.
The table below shows the threshold frequency f_0 and the work function φ for various metals.

metal	**A**	**B**	**C**	**D**	**E**
f_0 / 10^{14} Hz	4.5	5.6	6.5	8.0	9.7
φ / eV	1.9	2.3	2.7	3.4	4.1

Fig. 27 shows the data points for the metals **A**, **B**, **D** and **E** plotted on a φ against f_0 grid.

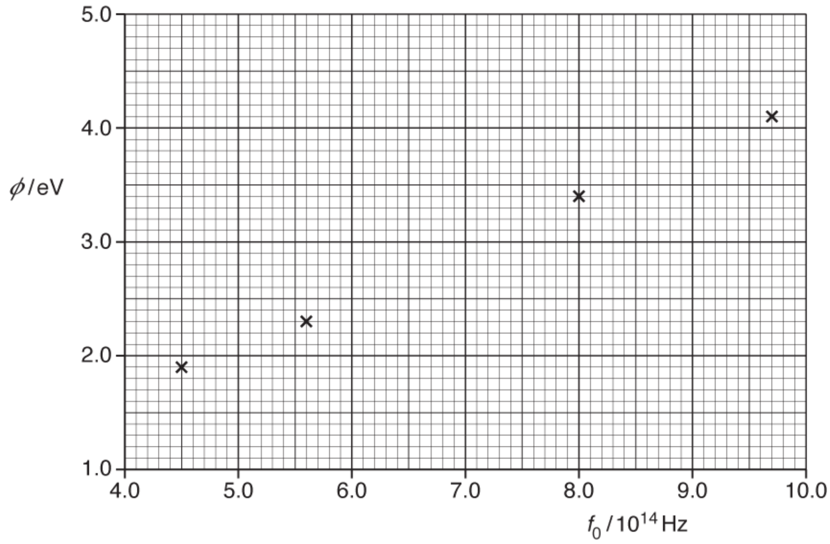

Fig. 27

i. Use Einstein's photoelectric equation to show

$$\varphi = hf_0$$

where h is the Planck constant.

[1]

ii. Plot the data point for **C** on Fig. 27 and draw the straight line of best fit.

[1]

iii. Use Fig. 27 to determine the experimental value for h.

h = ... J s **[2]**

iv. Explain, without doing any calculations, how you could use Fig. 27 to determine the percentage uncertainty in *h*.

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[2]

4. * A gold leaf electroscope is used to demonstrate the photoelectric effect. A zinc plate is placed on top of the electroscope. The zinc plate is negatively charged as shown in Fig. 7.

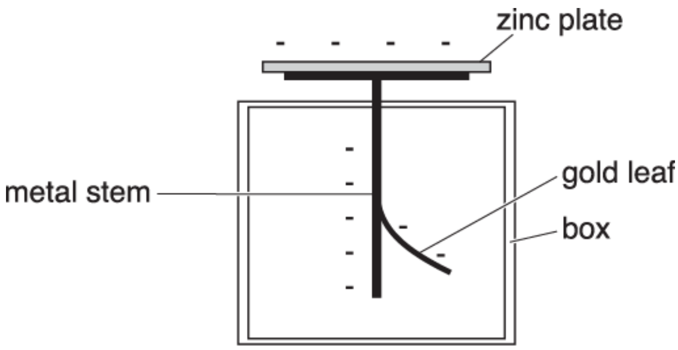

Fig. 7

White light from a table lamp is allowed to fall on to the electroscope from a distance of 10.0 cm. The experiment is then repeated with light from a distance of 4.0 cm. Both experiments are then repeated with ultraviolet radiation. The electroscope is fully charged before each experiment.

The observations are recorded in Table 7.

Incident radiation	**Observations**
Light at a distance of 10.0 cm	Gold leaf takes a very long time to fall
Light at a distance of 4.0 cm	Gold leaf takes a very long time to fall
Ultraviolet radiation at a distance of 10.0 cm	Gold leaf falls quickly
Ultraviolet radiation at a distance of 4.0 cm	Gold leaf falls very quickly

Table 7

Explain how these observations demonstrate the photoelectric effect and provide evidence for the particulate nature of electromagnetic radiation.

[6]

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5. Fig. 27.1 shows the *I-V* characteristic of an LED designed to emit blue light.

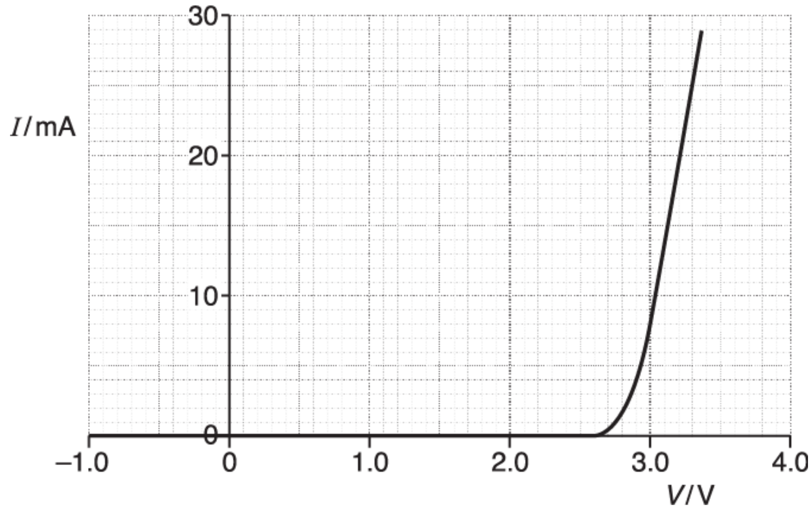


Fig. 27.1

A student uses the LED with the characteristic shown in Fig. 27.1 to construct the circuit shown in Fig. 27.2.

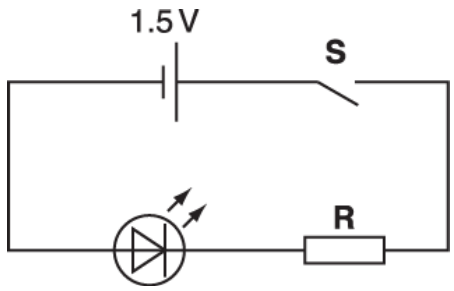


Fig. 27.2

A suitable resistor **R** is used in the circuit. The cell has electromotive force (e.m.f.) of 1.5 V and negligible internal resistance.
The LED fails to emit any light when the switch **S** is closed.
Explain why the circuit does not work and modify the design of the circuit so that the LED is lit when **S** is closed.

-- **[3]**

6. * The Planck constant h can be measured in an experiment using light-emitting diodes (LEDs).

Each LED used in the experiment emits monochromatic light. The wavelength λ of the emitted photons is determined during the manufacturing process and is provided by the manufacturer.

When the p.d. across the LED reaches a specific minimum value V_{min} the LED suddenly switches on emitting photons of light of wavelength λ.

V_{min} and λ are related by the energy equation $eV_{min} = hc / \lambda$.

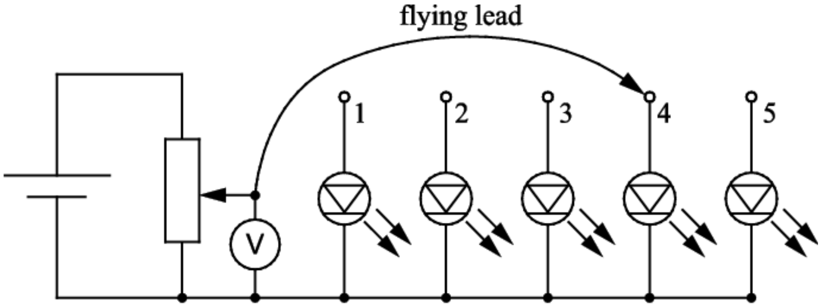


Fig. 7.1

LED	**λ / nm**	**V_{min} / V**
1 red	627	1.98
2 yellow	590	2.10
3 green	546	2.27
4 blue	468	2.66
5 violet	411	3.02

Discuss how you could use the circuit of **Fig. 7.1** to determine accurate values for V_{min} and how data from the table can be used graphically to determine a value for the Planck constant.

[6]

7. This question is about an experiment to determine the Planck constant using LEDs. To achieve a reliable value it is important to measure the value at which the LEDs **just** turn on, the threshold voltage.

i. Describe **one** technique you could use to measure the threshold voltage for LEDs.

[2]

ii. Draw a diagram of a circuit you would use to make these measurements.

[1]

8.

Two students, Alice and Bob, determined the wavelength of light emitted by different LEDs, and Bob uses their data to plot the graph of Fig. 8.2.

The values of E, the minimum energy needed to emit a photon, were obtained by measuring the minimum p.d. that would allow the LED in question to emit light. The gradient of the bestfit straight line should be the Planck constant, h.

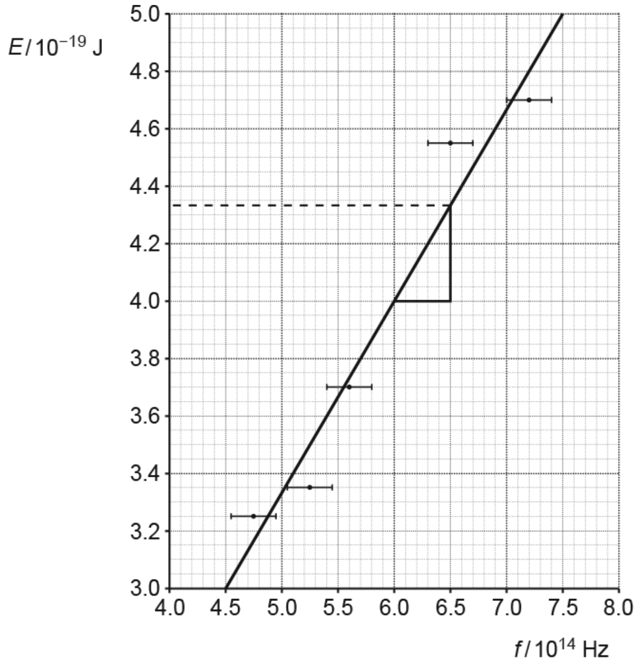


Fig. 8.2

Bob's analysis is shown on the graph of Fig. 8.2 and in the box following.

$$h = \text{gradient} = \frac{4.33 \times 10^{-19} - 4.0 \times 10^{-19}}{0.5 \times 10^{14}} = 6.6 \times 10^{-34}\ \text{J s}$$

This is exactly the same as the data book, so the experiment worked well.

Evaluate his analysis of the data from the experiment.

[6]

Note: Spome parts of the following question relates to theory only on the Physics B specification.

9(a). Lizzie has bought a new lens for her camera. It is marked with the focal length 50 mm (Fig. 8.1).

She wants to measure its focal length as accurately as possible to see if this value is correct.

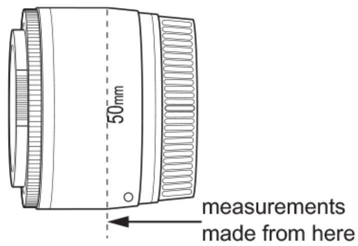


Fig. 8.1

The lens is made up of several different parts fixed inside a plastic case, and Lizzie cannot tell exactly where the centre of the lens is. She decides to make measurements from the top of the ‘5’ as shown.

Lizzie realises that measuring from this point may introduce a systematic error in her data. Explain the term *systematic error* and state how it will affect values of the object distance *u* and the image distance *v* that she obtains.

[3]

(b). Lizzie uses the arrangement in Fig. 8.2 to measure object (u) and image (v) distances.

As an object, she marks a black letter **X** on a thin sheet of paper.

The image is formed on a sheet of white card.

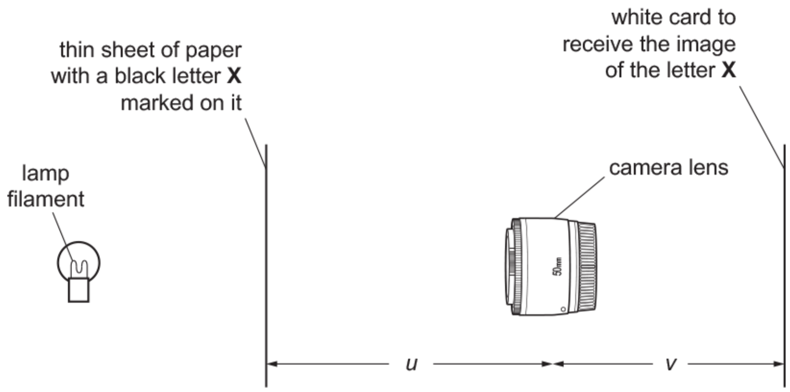


Fig. 8.2

Lizzie finds that a clear image can be seen on the white card over a range of values of v. She records this for four repeats at each chosen image position.
Here are her results for u = –37 cm.

smallest v / cm	34	35	34	36
largest v / cm	41	41	40	42

Use these data to find the best estimate of v and Δv for u = –37 cm.
Explain your working.

v = ... ± .... cm **[2]**

(c). Show that the lens equation for a converging lens of power P should result in a straight-line graph with gradient 1 and y-axis intercept P if $\frac{1}{v}$ is plotted on the y-axis for a range of values of $\frac{1}{u}$ on the x-axis.

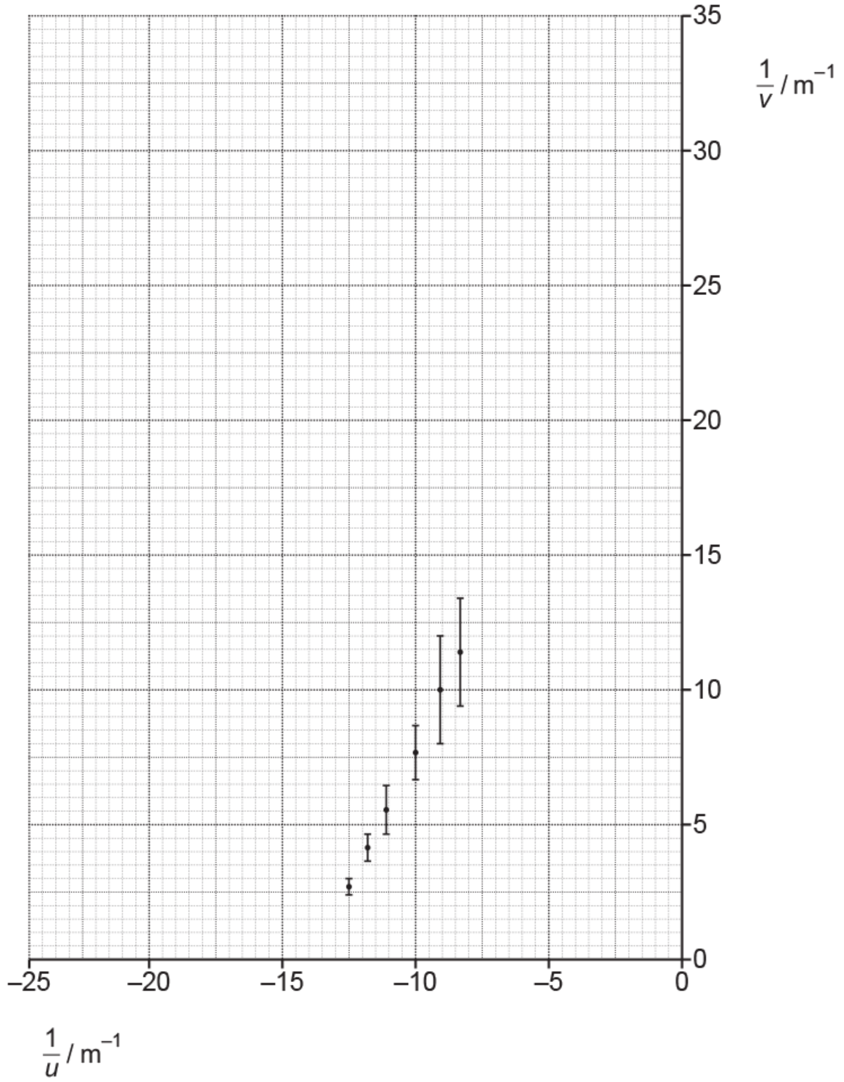
[2]

(d). In her experiment, Lizzie obtains the following set of values of v and Δv for each chosen value of u.

Complete the last two columns and plot the missing data on the graph.

u / m	v / m	Δv / m	$\frac{1}{u}$ / m^{-1}	$\frac{1}{v}$ / m^{-1}	$\Delta\left(\frac{1}{v}\right)$ / m^{-1}
–0.080	0.37	0.04	–12.5	2.70	0.3
–0.085	0.24	0.03	–11.8	4.17	0.5
–0.090	0.18	0.03	–11.1	5.55	0.9
–0.10	0.13	0.02	–10.0	7.69	1
–0.11	0.10	0.02	–9.09	10.0	2
–0.12	0.088	0.01	–8.33	11.4	2
–0.14	0.072	0.008	–7.14		
–0.16	0.063	0.007	–6.25		

[3]



(e). * Use the graph to find the maximum and minimum values of the gradient and the y-axis intercept and to evaluate the findings of the experiment.

[6]

END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			Use a polaroid / polarising filter Rotation will change intensity	B1B1	 **Allow** brightness / light
			Total	**2**	
2			**Level 3 (5–6 marks)** Clearly labelled diagram. Procedure is correct including appropriate measurements Analysis is correct and includes A5. (6 marks) Any point omitted or incorrect (5 marks). *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Good diagram. Most measurements made Some analysis. (4 marks) Any point omitted or incorrect (3 marks). *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Basic diagram with incomplete labels. Some measurements. Limited analysis. (Maximum 2 marks) *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 x 6	**Diagram** 1. Labelled diagram of glass block & ray box 2. Incident and refracted rays shown 3. Normal shown and correct *i* and *r* **Procedure** 1. Block placed on paper 2. Incident and refracted rays marked 3. Angles measured using a protractor **Analysis** 1. sin *i* and sin *r* calculated 2. sin *i* against sin *r* graph plotted 3. Straight line of best fit drawn 4. gradient = refractive index *(n)* 5. Error bars drawn to find the gradient
			Total	**6**	
3		i	$hf = \phi + KE_{(max)}$and kinetic energy = 0 (at f_0) (therefore $\phi = hf_0$)	**B1**	
		ii	Data point (to with ½ small square) and a reasonable straight (best-fit) line drawn with a straight edge / ruler	**B1**	**Not** freehand / wobbly line

		iii	Correct conversion from eV to J using 1.6×10^{-19} (gradient = *h*) gradient determined **and** *h* = (6.4 to 7.4) × 10^{-34} (J s)	**B1** **B1**	**Note** this can be a single value of ϕ or $\Delta\phi$ **Allow** value of *h* must be given to 2 or 3 SF
•		iv	Draw a worst-fit line (and determine gradient / *h*) (AW) % uncertainty = (*h* from **biii** - *h* from worst line) × 100 ÷ *h* from **biii** **or** Calculate the average *h* using f_0 and ϕ (values) % uncertainty = (½ range ÷ average *h*) × 100	**B1** **B1** **B1** **B1**	**Allow** (line of) maximum / minimum gradient **Ignore** sign **Allow** gradient instead of *h*
			Total	**6**	
4			**Level 3 (5–6 marks)** Clear explanation of observations **and** clear evidence of particulate nature of electromagnetic waves *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear explanation of observations **or** clear evidence of particulate nature of electromagnetic waves **or** has limited explanation of observations and limited evidence of particulate nature of EM radiation *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Has limited explanation of observations **or** limited evidence of particulate nature of EM radiation *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.*	B1	**Indicative scientific points may include:** **Explanation of Observations** • Discharge due to the emission of electrons / negative charge • Intensity depends on distance • <u>Rate</u> of incident photons is more at smaller distances • Greater intensity / rate of uv photons linked to quicker fall • uv causes instantaneous discharge • No effect with light • Intensity of light has no effect on the discharge • Natural discharge over a long period of time **Evidence of particulate nature of em** • Wave theory suggests leaf would fall with light • Photon as packet of energy • One to one interaction • uv <u>photon</u> greater energy than work function / greater frequency than threshold frequency • Light <u>photons</u> have less energy than the work function

			0 marks No response or no response worthy of credit.		• $E = hf$ / photon energy depends on frequency • Energy of photon independent of intensity • Energy conserved in interaction • Einstein's equation (words or symbol)
			Total	**6**	
5			(The circuit does not work because) the LED is reverse biased / incorrect polarity of the cell (AW)	B1	**Allow**: (For the circuit to work) the LED must be forward-biased / ‘reverse the LED’ / ‘reverse the cell’
			V must be greater than 2.6 (V for the LED to be lit)	B1	**Allow** ±0.1 V **Not** V must be equal to / ‘at least‘ 2.6 V **Allow** this mark even if the LED is reverse biased
			Use two (or more 1.5 V) cells (in series) / use a supply greater than 2.6 (V) / use a 3.0 (V) supply	B1	**Note**: This B1 mark can be scored on Fig. 27.2 **Allow** this mark even if the LED is reverse biased
			Total	**3**	
6			***Level 3 (5–6 marks)** at least E3,4 and 2 or 5 at least P1,2 and 5 *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** expect 3 points from E and 2 points from P or 2 points from E and 3 points from P *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** at least 2 points from E and 1 point from P or vice versa. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1	**Experiment (E)** 1. Adjust the potential divider to low or zero voltage 2. connect flying lead to one LED 3. increase voltage until LED just lights or strikes 4. repeat several times and average to find V_{min} 5. repeat for each LED 6. shield LED inside opaque tube to judge strike more accurately. **Processing (P)** 1. a graph of V_{min} against $1/\lambda$ will be a straight line 2. through the origin 3. so need to calculate values of $1/\lambda$ 4. then draw line of best fit through origin 5. gradient $G = V_{min}\,\boldsymbol{\lambda} = hc/e$ 6. hence $h = eG/c$
			Total	**6**	

7		i	1 a sensitive ammeter in series with LED as V increased find the p.d. value when it starts conducting (1) 2 black-out and shaded vision tube to judge V value when visible light is first observed as V increased (1)	2	accept galvanometer or μA or mA meter **accept** 1 & 2 either way round
		ii	fully functioning circuit with variable supply / potential divider, LED with voltmeter in parallel (if ammeter used must be in series)	1	with series current limiting resistor good but **NOT** a series variable resistor to control circuit
			Total	**3**	
8			**(Level 3) (5–6 marks)** Recognises that the gradient is correct, but poor use has been made of the best-fit line. Comments on the inadequate allocation of uncertainty bars in terms of spread of data/best-fit line. May criticise ignoring uncertainties in *E*. Suggests way to get uncertainty in *h* and makes recommendations for improving the data, e.g. checking points which are well off the line, adding extra measurements for different LEDs. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **(Level 2) (3–4 marks)** Recognises that the value is correct and that there is considerable spread in the data. May comment on the inadequate gradient triangle. May state that line does not pass through all uncertainty bars but does not follow that through to action needed to correct it. *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **(Level 1) (1–2 marks)** Recognises that the value is correct, but does not comment on shortcomings of graphical analysis or use of uncertainties. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **(0 marks)** Insufficient or irrelevant science. Answer not worthy of credit.	**[6]**	**Indicative scientific points may include:** **Calculation of *h*** • Final value is close to expected value • Best-fit straight line is reasonable • Triangle used to calculate gradient is too small • No attempt to calculate uncertainty in *h* • Suggested method for finding Δ*h*, e.g. drawing maximum or minimum possible gradient to get extreme value, or use of percentage uncertainty in data • Candidate may check actual gradient 6.7×10^{-34} J s (Check the graph on the QP) **Spread of data and uncertainty bars** • uncertainty bars belie the spread observed in the data • could be errors in data • or uncertainties could have been underestimated • no attempt to include uncertainties in *E* • these could have been significant • should have checked data, e.g. 4.5×10^{-19} J • could have taken extra readings for different LEDs • Candidate may attempt to check Δ*h* value (Check the graph added to the response) **Use the L1, L2, L3 annotations in Scoris; do not use ticks.**
			Total	**6**	

<table>
<tr>
<td>9</td>
<td>a</td>
<td></td>
<td>Correct explanation of systematic error ✓

(For any pair of readings), Δu will be the same size as Δv ✓

Δu & Δv will be in opposite directions ✓</td>
<td>3</td>
<td>Must have the idea that it is built into the system of measurement used i.e. not measuring from the (optical) centre but from some point to one side of it. May refer to calibration or zero error.

e.g. if $|u|$ is too small, v will be too big by the same amount</td>
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<tr>
<td></td>
<td>b</td>
<td></td>
<td>Taking all 8 values, range of v is (34 cm, 42 cm)
Δv = (42 cm - 34 cm)/2 = 4 cm ✓

mean v = (34 cm + 42 cm)/2 = 38 cm ✓

OR

mean v = (34+35+34+36+41+41+40+42)/8

= 38 cm rounded to nearest cm✓</td>
<td>2</td>
<td>Correct answer is 38 cm ± 4 cm and can be obtained in different ways.

If mean quoted as 37.9 cm, accept either 42 cm - 37.9 cm = 4.1 cm or 37.9 cm – 34 cm = 3.9 cm for Δv
ALLOW mean = (mean v_{max} – mean v_{min})
= 37.8 cm</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td></td>
<td>$\frac{1}{v}=\frac{1}{u}+\frac{1}{f}=\frac{1}{u}+P$ ✓

$y = mx + c$ so m = 1 and $c = P$ if $y = 1/v$ and $x = 1/u$ ✓</td>
<td>2</td>
<td>Rewriting the lens equation in terms of u, v and P

Identifying m and c from the lens equation</td>
</tr>
<tr>
<td></td>
<td>d</td>
<td></td>
<td>$1/v$ values of 13.9 m^{-1} AND 15.9 m^{-1} respectively ✓

At least one uncertainty in $1/v$ correctly found ✓

Points and uncertainty bars correctly plotted with e.c.f. ✓

<table>
<tr><th>v</th><th>Δv</th><th>v_{min}</th><th>v_{max}</th><th>$1/v$</th><th>$1/v_{min}$</th><th>$1/v_{max}$</th><th>diff/2</th><th>$1/v-1/v_{max}$</th><th>$1/v_{min}-1/v$</th><th>$\Delta(1/v)$</th></tr>
<tr><td>0.072</td><td>0.008</td><td>0.064</td><td>0.08</td><td>13.889</td><td>15.625</td><td>12.5</td><td>1.5625</td><td>1.389</td><td>1.736</td><td>1, 2, 2</td></tr>
<tr><td>0.063</td><td>0.007</td><td>0.056</td><td>0.07</td><td>15.873</td><td>17.857</td><td>14.286</td><td>1.786</td><td>1.587</td><td>1.984</td><td>2, 2, 2</td></tr>
</table>
</td>
<td>3</td>
<td>ALLOW 13.89 m^{-1} AND 15.87 m^{-1}. See table below.

Allow 1 m^{-1} or 2 m^{-1}

Tolerance ± half a small square.</td>
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<tr>
<td></td>
<td>e</td>
<td></td>
<td>(Level 3) (5 – 6 marks)
Maximum and minimum gradients and at least one intercept value found with sensible comparison of gradient with 1 and intercept with 20 m^{-1}. Realises that data contradicts expected results, even though graph looks good. Recognises that systematic errors may be responsible for incorrect gradient and intercept.
There is well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.

(Level 2) (3 – 4 marks)
Two reasonable lines drawn and at least one</td>
<td>[6]</td>
<td>Indicative scientific points may include:
Analysis of graph

• Max gradient found (I get 2.4)
• Min gradient found (I get 1.7)
• Max y-axis intercept found (I get 32.0 m^{-1})
• Min y-axis intercept found (I get 25.7 m^{-1})

Comparison with expected results

• Expected gradient = 1 is lower than the minimum found
• Expected y-axis intercept = power of lens with 50 mm focal length</td>
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			value each of values of gradient and intercept found correctly. Other evaluation superficial, as level 1. *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **(Level 1) (1 – 2 marks)** At least one acceptable line drawn through data. Gradient found, possibly with too small a triangle. Intercept read correctly. Unlikely to refer to expected values, and evaluation may be simplistic, e.g. repeat experiment. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **(0 marks)** No response or no response worthy of credit.		• $1/(50\times10^{-3}$ m) = 20 D • Expected *y*-axis intercept is lower than the minimum found **Evaluation of the graph** • Data all fall within a reasonable straight line with no obvious outliers • Uncertainty decreases with larger $\|1/u\|$ • i.e. when object is closer to lens, results are more uncertain **Evaluation of the procedure followed** • systematic error (as in part (a)) could explain the 'wrong' gradient and intercept • random uncertainties would create greater spread of data but should not make gradient and intercept so wrong. • Need to have more data to clarify, e.g. more data points, or trying a different zero of measurements on the lens body. **Use the L1, L2, L3 annotations in Assessor; do not use ticks.**
			Total	**16**	

