1.

(a) State, **in terms of energy**, the meaning of each term in Einstein's photoelectric equation

$$E_{k\max} = hf - \phi.$$

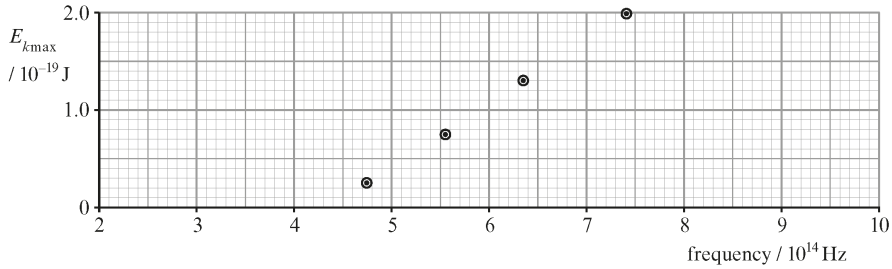
(i) $E_{k\max}$ .... [1]

(ii) hf .... [1]

(iii) ϕ ....

.... [1]

(b) Monochromatic light of frequency 7.40×10^{14} Hz is shone on to a caesium surface, and $E_{k\max}$ is measured. The procedure is repeated for three other frequencies, enabling four points to be plotted on the grid below.



(i) Showing your working, determine from the grid above

(I) a value for the Planck constant, [2]

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(II) the work function of caesium. [2]

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(ii) When a lithium surface is used instead of a caesium surface, $E_{k\max}$ is found to be 0.40×10^{-19} J for light of frequency 7.40×10^{14} Hz.

(I) Draw the expected line of $E_{k\max}$ against frequency on the same grid. [2]

(II) This line cannot be checked satisfactorily by experiment using visible light. Name the region of the electromagnetic spectrum which is required. [1]

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(III) What is different about lithium, as compared to caesium, which makes it necessary to use this region of the electromagnetic spectrum? [1]

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2.

(a) Define the *work function* of a metal surface. [1]

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(b) The work function of sodium is 3.8×10^{-19} J. Use Einstein's photoelectric equation to find

(i) the lowest frequency of light which will eject electrons from a sodium surface, [2]

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(ii) the maximum kinetic energy of electrons emitted from a sodium surface when light of frequency 7.0×10^{14} Hz is shone on to the surface. [2]

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(c) (i) The answer to *(b)*(ii) is unaffected if the *intensity* of light is increased. Explain, in terms of *photons*, why this should be the case. [2]

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(ii) What aspect of photo-electric emission *is* affected by the light intensity? [1]

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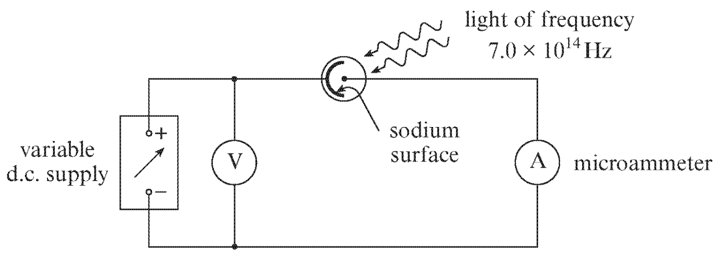
(d) The diagram shows apparatus set up to check experimentally the answer to *(b)*(ii). Describe how you would make this check. [4]



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3.

(a) Here is a summary of a theory (now considered incorrect) to account for the photoelectric effect:

> "The electrons in a surface gradually gain energy from light waves falling on the surface. After a time they will have gained enough energy to escape. The greater the intensity of the light waves the greater the maximum kinetic energy of the emitted electrons."

State some ways in which Einstein's explanation (in terms of photons) of the photoelectric effect differs from the theory above. [4]

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(b) The work function of sodium is 3.8×10^{-19} J.

(i) Calculate the maximum kinetic energy of electrons emitted from a sodium surface irradiated with ultraviolet radiation of frequency 8.7×10^{14} Hz. [2]

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(ii) Discuss whether or not this maximum kinetic energy would change if the surface were also irradiated **at the same time** with radiation of frequency 8.5×10^{14} Hz. [2]

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(iii) Determine whether or not visible light can cause the emission of electrons from a sodium surface, giving your reasoning and conclusion. Take the range of visible wavelengths to be 400 nm to 700 nm. [3]

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4.

(a) When ultraviolet radiation of high enough frequency falls on a tin plate (held by an insulating support) the plate acquires a charge. Explain, in terms of electrons and photons, why this happens, and whether the charge is positive or negative. [3]

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(b) The *work function* of tin is 7.1×10^{-19} J.

(i) What is meant by the work function of a metal? [1]

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(ii) Calculate the minimum frequency of ultraviolet radiation needed for photoelectric emission from tin. [2]

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(iii) Calculate the **frequency** of ultraviolet radiation needed for the emitted electrons to have a maximum kinetic energy of 1.5×10^{-19} J. [2]

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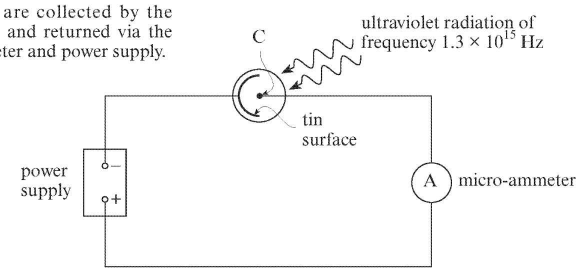
(c) In the set-up shown, assume that all the electrons emitted from the tin surface are collected by the electrode C, and returned via the micro-ammeter and power supply.



(i) The micro-ammeter reads 0.64 μA (0.64×10^{-6} coulombs per second). Show that 4.0×10^{12} electrons are emitted per second. [1]

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(ii) Only 1 in 1200 of the incident photons causes emission of an electron. By considering the energy of an individual photon, calculate the ultraviolet energy per second falling on the tin surface. [4]

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5.

4. *(a)* The *work function* of caesium is 3.4×10^{-19} J.

Calculate the lowest *frequency* of light that will cause photo-electric emission from a caesium surface. [2]

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(b) Light of frequency 7.4×10^{14} Hz is shone on to a caesium surface.

(i) Calculate the maximum kinetic energy, KE_{max}, of the emitted electrons for this frequency of light. [2]

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(ii) Explain **in physical terms** why KE_{max} is less than the energy of an incident photon. [2]

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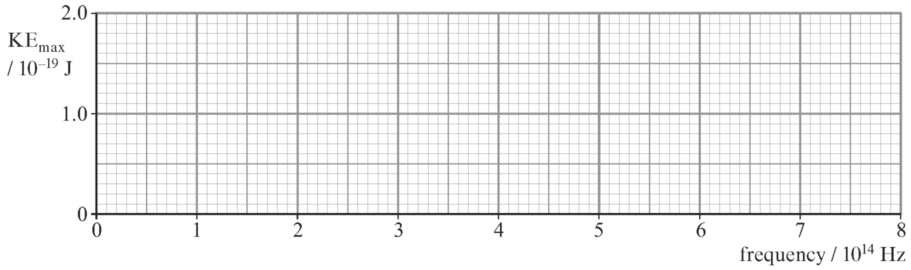
(c) (i) Making use of your answers to *(a)* and *(b)*(i), draw a graph, on the axes provided, to show how KE_{max} would depend on the frequency of incident light. [2]



(ii) What does the gradient of this graph represent? [1]

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(iii) On the same axes sketch a graph that could be obtained for a metal with a greater work function than caesium. **Label this graph '(iii)'.** [1]

5. *(a)* Magnesium has a *work function* of 5.9×10^{-19} J. What does this statement mean? [1]

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(b) Calculate the maximum kinetic energy of electrons ejected from a magnesium surface by ultraviolet radiation of frequency 1.16×10^{15} Hz. [2]

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(c) Explain in physical terms why electrons are not emitted when radiation of frequency 8.21×10^{14} Hz (instead of the original frequency) falls on a magnesium surface. Support your answer with a calculation. [2]

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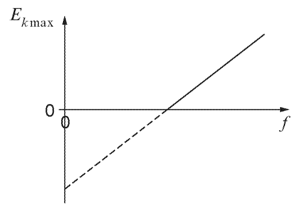
(d) The graph shows how the maximum kinetic energy, $E_{k\max}$ of electrons ejected from a magnesium surface varies with the frequency, f, of ultraviolet radiation falling on the surface.



State the physical quantities represented by:

(i) the gradient; [1]

....

(ii) the intercept on the $E_{k\max}$ axis; [1]

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(iii) the intercept on the f axis. [1]

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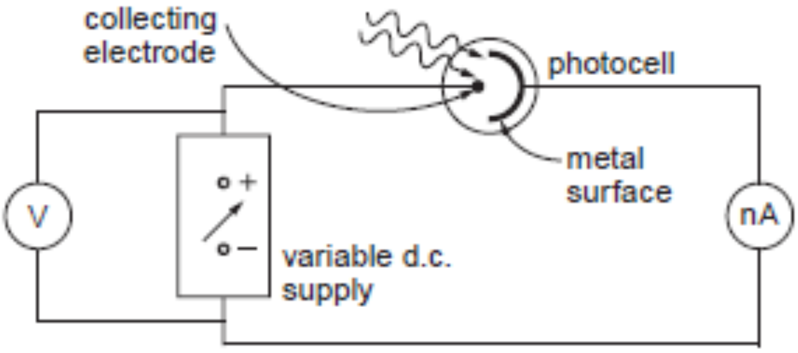
7\. **3.** Light is incident on a photoelectric cell as shown.



(a) Explain why a current is detected by the ammeter. [3]

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(b) The work function of the metal surface is 2.7 eV and electrons are emitted with a maximum kinetic energy of 1.2 eV.

Calculate the frequency of the incident photons. [3]

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(c) (i) Explain how you would modify and use the circuit opposite to measure the stopping potential. [3]

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(ii) The metal surface of the photocell is radioactive and emits alpha particles some of which arrive at the collecting electrode. Explain briefly what effect this would have on measuring the stopping potential and what could be done to reduce this effect. [3]

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8.

(a) Einstein's photoelectric equation is $E_{k\,\max} = hf - \phi$

State, in terms of *energy,* the meaning of each term in the equation.

(i) $E_{k\,\max}$ ....

[1]

(ii) hf ....

[1]

(iii) ϕ ....

....

[1]

(b) The minimum frequency of radiation which will eject electrons from a surface is f_0. Determine, as a multiple of f_0, the frequency of radiation which will eject electrons with maximum kinetic energy 2ϕ from the same surface. [2]

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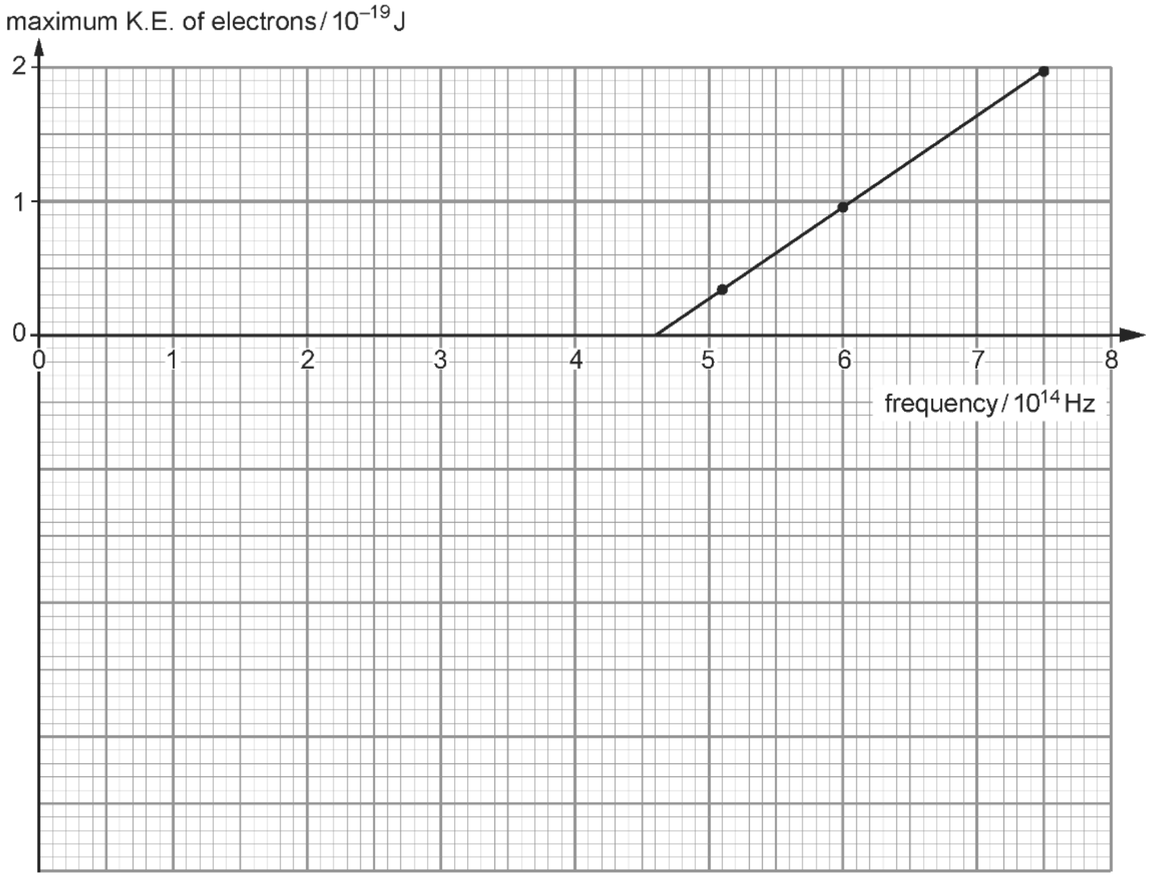
(c) A student determines the maximum kinetic energy of electrons ejected from a caesium surface by incident light of three frequencies, and plots the straight line graph shown.



(i) Determine from the graph values for:

(I) the Planck constant; [2]

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(II) the work function of caesium. [1]

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(ii) The student starts to repeat the process for a sodium surface, but runs out of time after obtaining data for one graph point:

$$f = 6.0 \times 10^{14}\,\text{Hz}, \quad E_{k\,\max} = 0.32 \times 10^{-19}\,\text{J}$$

Obtain a value for the work function of sodium, showing your reasoning. [2]

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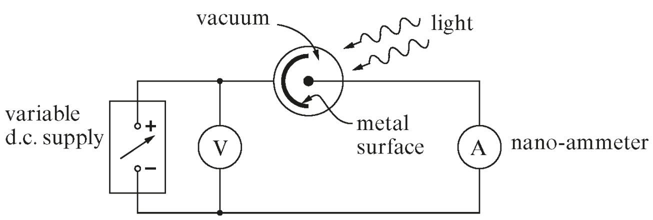
9.

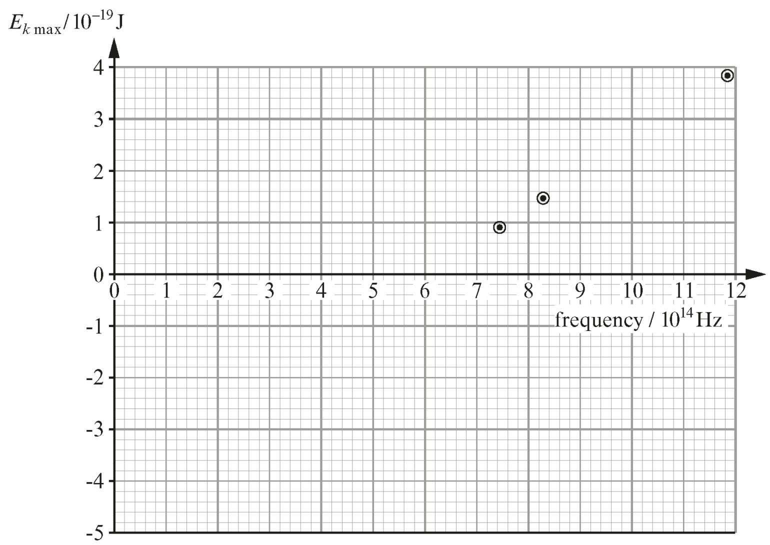
(a) (i) The threshold frequency for electrons to be emitted in the photoelectric effect is $f_o = \frac{\phi}{h}$. Explain, in terms of energy, why this is so. [3]

(ii) Explain why increasing the *intensity* of light will not increase the maximum kinetic energy, $E_{k\,max}$, of the emitted electrons. [2]

(b) Monochromatic light is shone on to a metal surface in a photocell connected as shown. Describe how you would find the maximum kinetic energy of the emitted electrons. [3]



(c) The experiment is carried out, using three known frequencies of light in succession, giving the points plotted on the grid.



(i) Calculate the gradient of the graph and check whether or not it has the expected value, giving your working and conclusion clearly. [2]

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(ii) The metal with the exposed surface in the photocell is known to be one of the five metals whose work functions are listed.

metal	caesium	potassium	sodium	barium	calcium
ϕ / 10^{-19} J	3.12	3.68	3.78	4.03	4.59

Use the graph to determine which of these metals is in the photocell, giving your reasoning. [2]

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10.

7. Einstein's photoelectric equation can be written as

$$E_{k\,max} = hf - \phi$$

(a) Explain what is meant by the term work function, ϕ . [2]

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(b) (i) Light of frequency 7.3×10^{14} Hz is incident on a sodium surface at a rate of $2.5 \times 10^{-10}\,\mathrm{J\,s^{-1}}$. Determine the number of photons per second incident on the sodium surface. [2]

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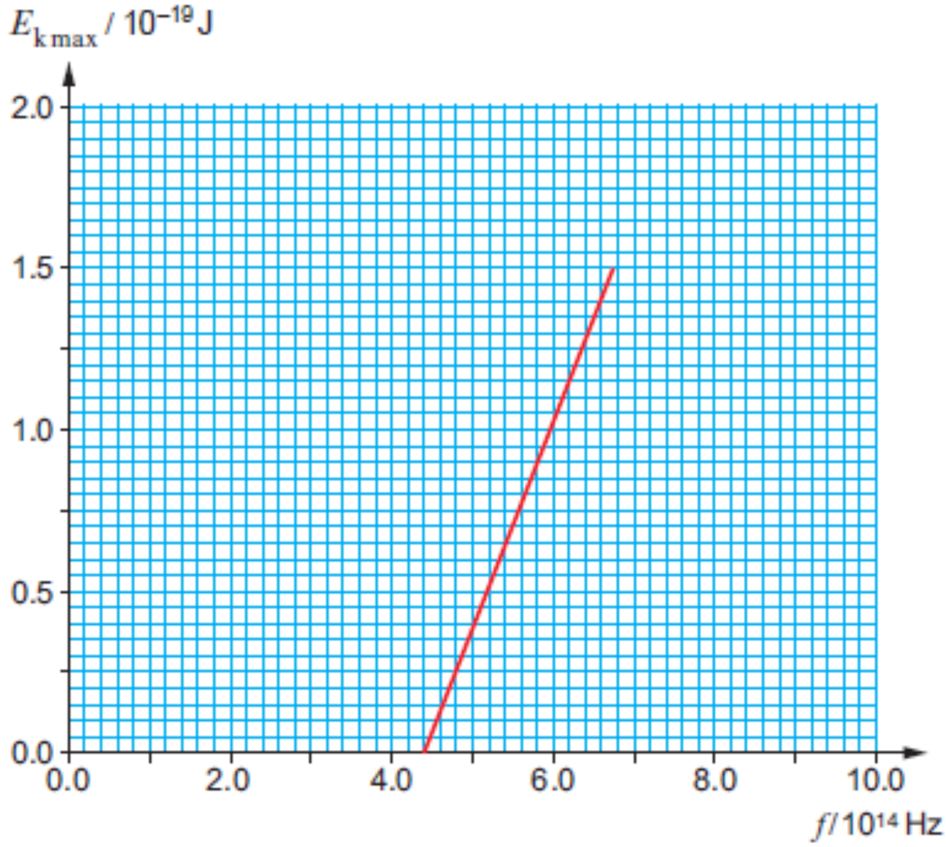
(ii) A graph of $E_{k\,max}$ against f for the sodium surface is given below.

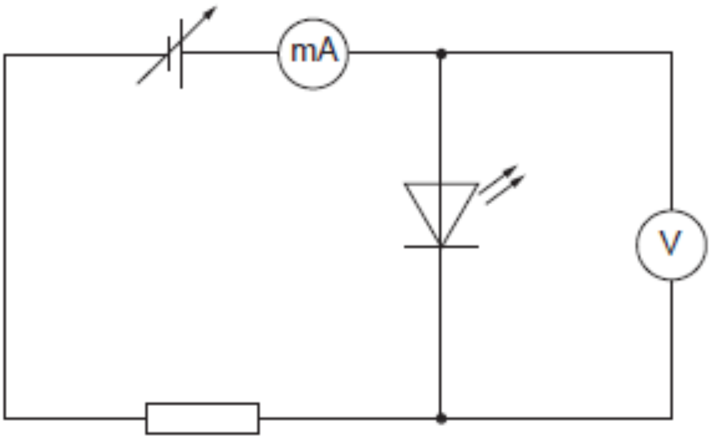


I. Calculate the work function of sodium. [2]

II. Draw a line on the graph to show how $E_{k\,max}$ varies with f for a metal which has a greater work function than sodium. [2]

III. The rate at which light falls on to the sodium surface is increased from $2.5 \times 10^{-10}\,J\,s^{-1}$ to $3.0 \times 10^{-10}\,J\,s^{-1}$. Explain clearly why the graph would not change. [2]

11. 7. (a) The following circuit is used to find the pd across an LED when it is switched on.



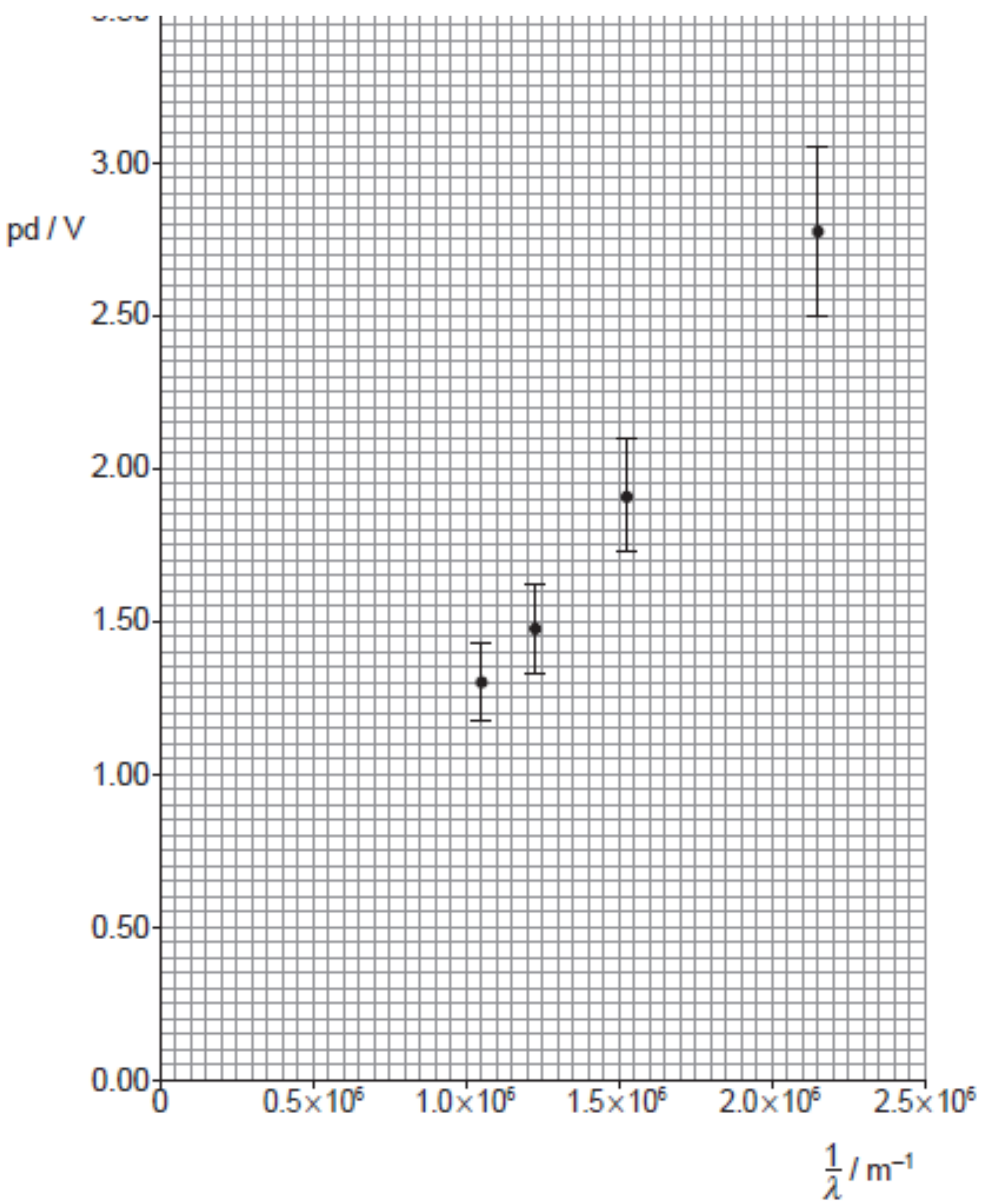
Aled decides that the LED is switched on when a current of 10.0 mA passes through it. He adjusts the variable power supply and records the switching-on pd. He repeats this procedure for different LEDs which emit light of different wavelengths. His results are tabulated below.

(i) **Complete** the table. [2]

Wavelength λ of LED / nm	$\frac{1}{\lambda}$ / m^{-1}	Switching-on pd / V (± 10%)
465	2.15×10^6	2.78 ± 0.28
569	.... $\times 10^6$	$2.26 \pm$ ....
660	1.52×10^6	1.91 ± 0.19
820	1.22×10^6	1.47 ± 0.15
890	.... $\times 10^6$	$1.44 \pm$ ....
950	1.05×10^6	1.29 ± 0.13

(ii) **Complete** the graph by plotting the **two** missing points whose values you have calculated together with their error bars. [2]

(iii) **Draw** the line of maximum gradient and the line of minimum gradient through the error bars. [2]



(b) Conservation of energy applied to an electron and photon involved in the light emitting process of the LED gives:

$$eV = \frac{hc}{\lambda}$$

(i) Use your two lines from *(a)*(iii) to obtain a value for the Planck constant along with its absolute uncertainty to an appropriate number of significant figures. [5]

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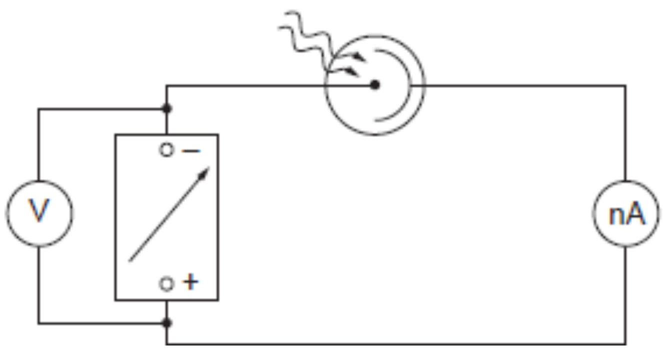
(ii) Explain to what extent Aled's data displayed in the graph confirm the relationship. [4]

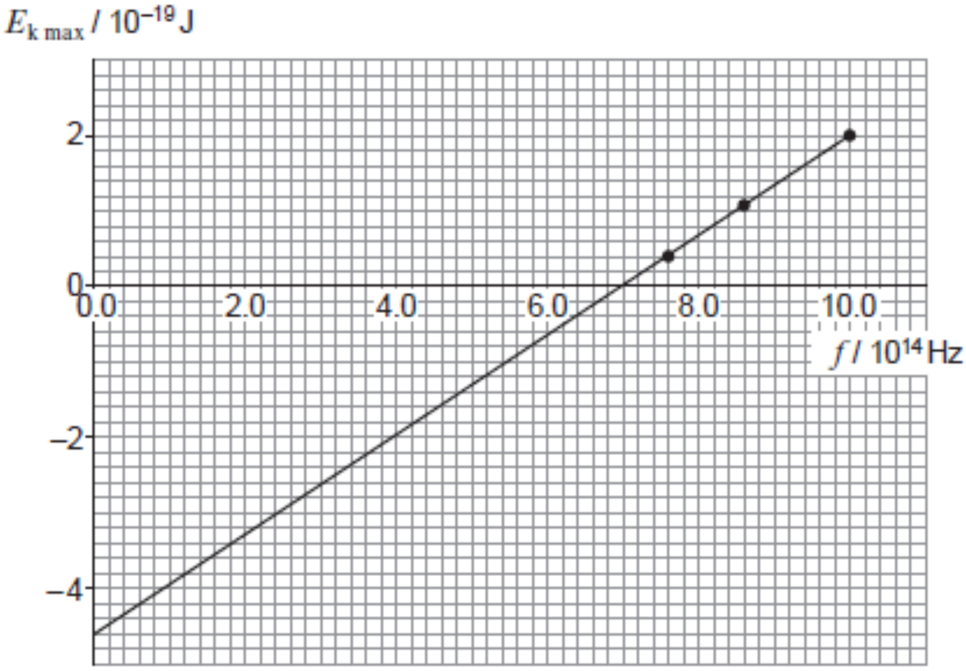
$$eV = \frac{hc}{\lambda}$$

(c) Suggest **one** reason why choosing a constant current of 10.0 mA is better than using your eye to detect the emitted radiation for these LEDs. [1]

(d) The Planck constant can also be determined using the photoelectric effect. Light of various frequencies is incident on a calcium photoelectric cell as shown and the maximum kinetic energy, $E_{k\,max}$, of the emitted electrons is determined for each frequency, f.



The following graph is obtained.



(i) Determine a value for the Planck constant. [2]

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(ii) Determine a value of the work function of calcium and explain why no data points are possible below a frequency of 6.9×10^{14} Hz. [3]

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12.

3. *(a)* (i) State what is meant by the photoelectric effect. [1]

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(ii) Einstein's photoelectric equation may be written as:

$$E_{k\,max} = hf - \phi$$

Explain this equation in terms of energy. [3]

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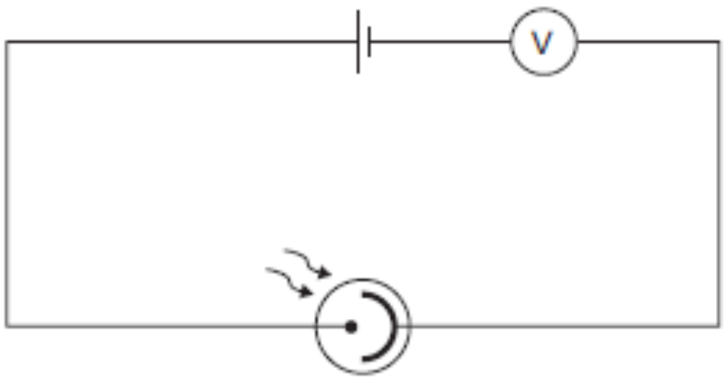
(b) Evaluate why the following circuit is incorrect and cannot be used to measure the maximum kinetic energy of the emitted electrons. [4]



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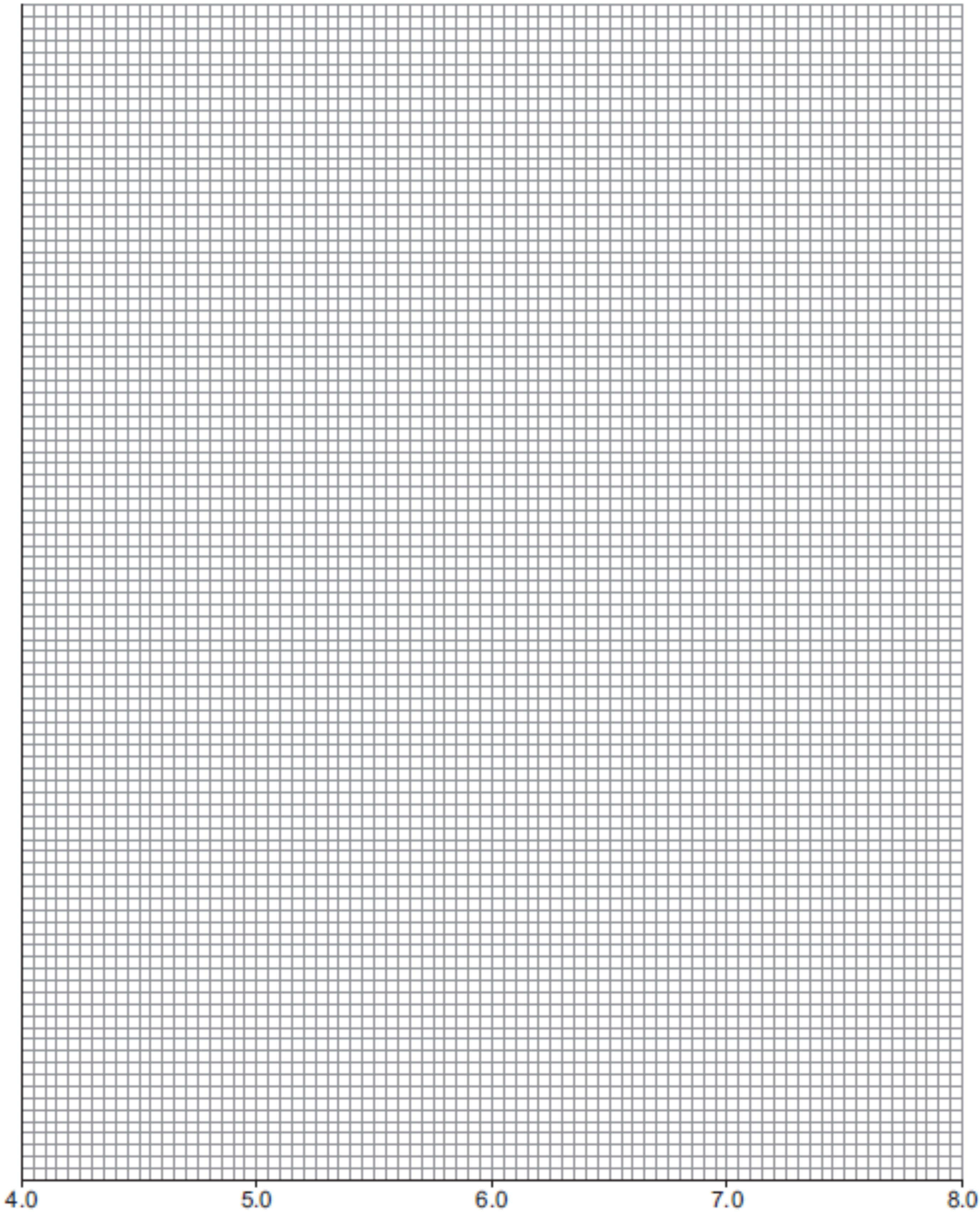
(c) Different frequencies of light are used with a correct circuit and the following results are obtained.

Frequency / 10^{14} Hz	5.1	6.0	6.9	7.5
$E_{k\,max}$ / 10^{-19} J	0.36	0.93	1.50	1.95

(i) Plot $E_{k\,max}$ (y-axis) against frequency (x-axis) on the grid below and draw a line of best fit through your data. [3]



(ii) Explain whether or not your graph is in agreement with Einstein's photoelectric equation. [3]

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(iii) Calculate a value for the Planck constant using the gradient of your graph. [3]

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(iv) An answer can be considered to be accurate if it is within 5% of the accepted value for the Planck constant. Evaluate whether your answer for the Planck constant can be considered to be accurate. [2]

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13. **8.** *(a)* (i) Light of frequency less than $\frac{\phi}{h}$ cannot eject electrons from a surface of work function ϕ, even if the light intensity is increased. Explain this in terms of photons. [3]

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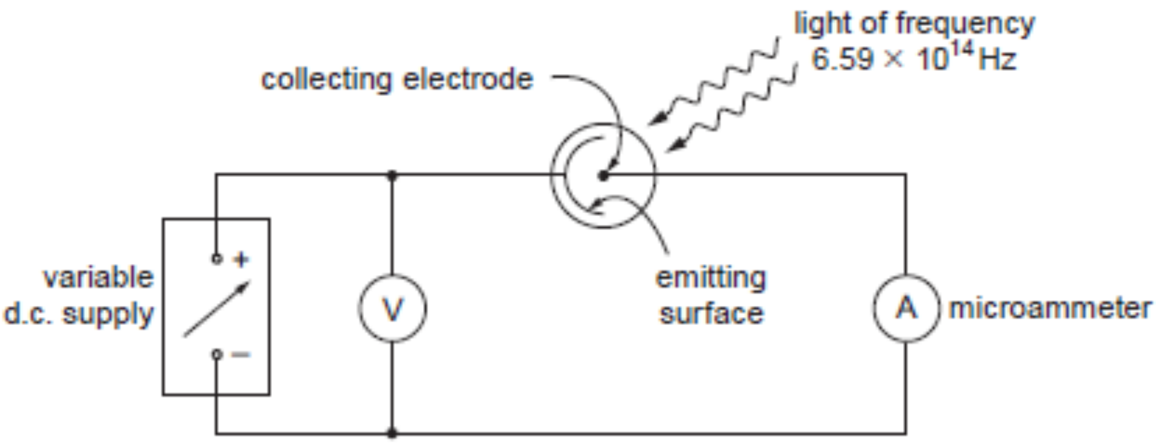
(ii) The emitting surface in a vacuum photocell is known to be made of one of the metals listed below (with their work functions).

Metal	caesium	potassium	barium	calcium	zinc
Work function / 10^{-19} J	3.12	3.68	4.03	4.59	5.81

The photocell is included in the circuit shown, and illuminated with light of frequency 6.59×10^{14} Hz.



With zero pd applied, the microammeter indicates a current. At some pd between 0 V and 0.35 V the microammeter reading drops to zero.

Determine which metal the emitting surface is made of, giving your reasoning clearly. [4]

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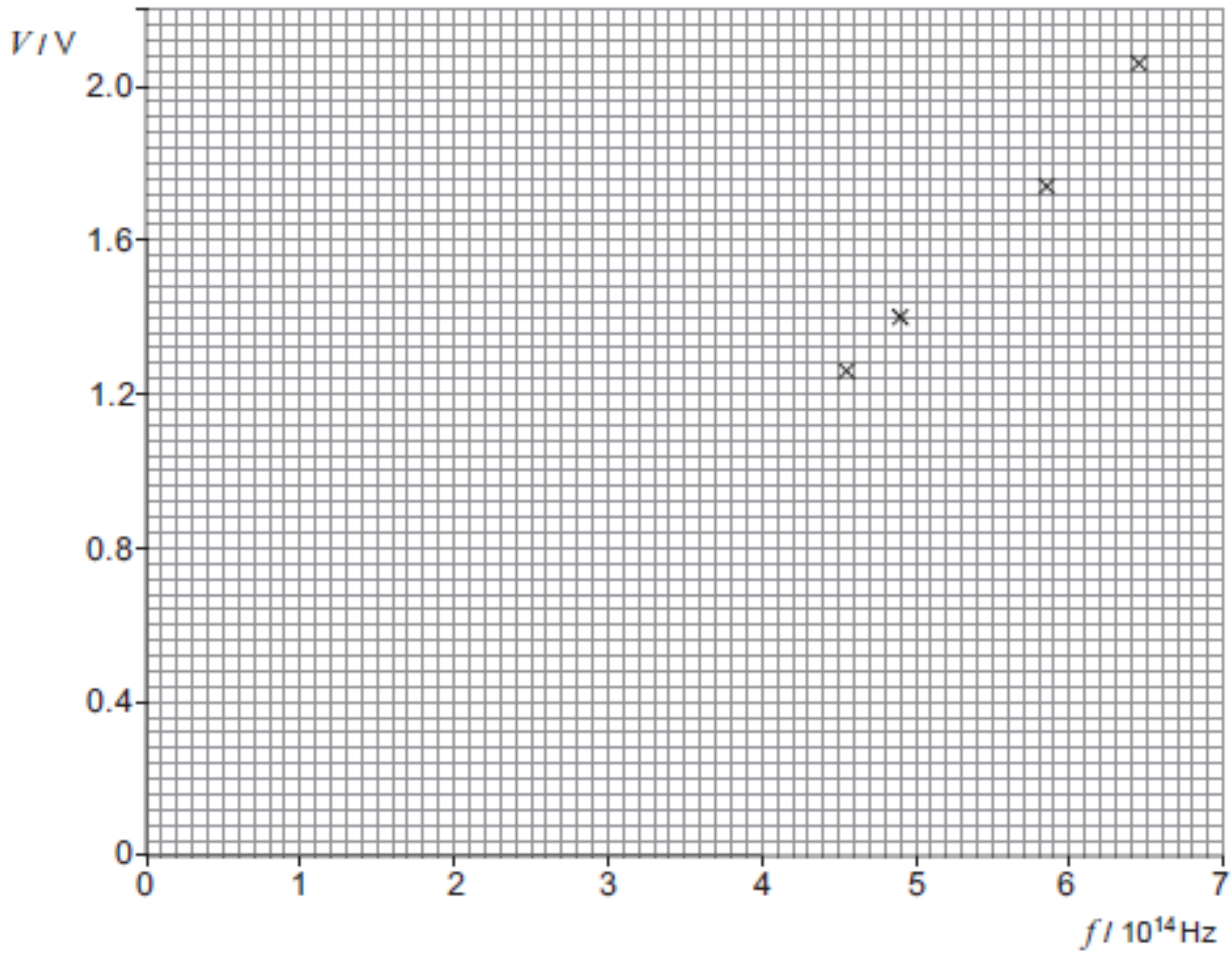
(b) Rachel varies the pd across a light-emitting diode (LED) and notes the value, V, for which she can just see light from the LED. She also notes the frequency, f, of the light, as supplied by the LED's makers. She does the same for three other LEDs and plots V against f (below).



It has been suggested that V and f are related by the equation:

$$V = \frac{h}{e} f$$

(i) **On the graph** draw the line of best fit. [1]

(ii) Discuss the extent to which the graph supports an equation of this form. [2]

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(iii) Determine the gradient of the graph, and hence a value for h to an appropriate number of significant figures. Assume that the equation predicts $\frac{\Delta V}{\Delta f}$ correctly. [3]
Show your working clearly.

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14. **5.** *(a)* Define the *work function* of a metal. [1]

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(b) The work function of caesium is 3.2×10^{-19} J. Show that the frequency of light that will eject electrons from a caesium surface with a maximum kinetic energy of 1.5×10^{-19} J is approximately 7×10^{14} Hz. [2]

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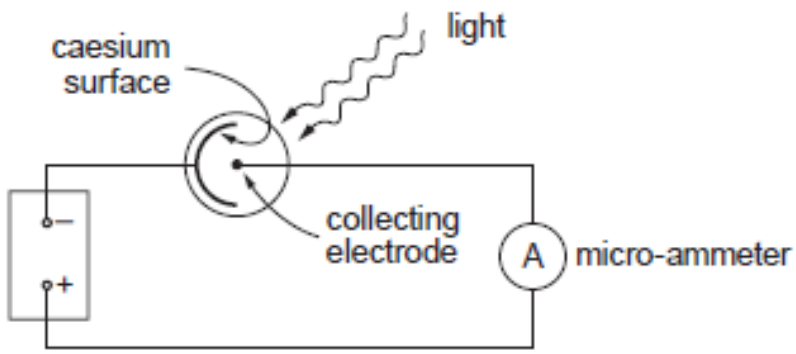
(c) The **same frequency** of light is shone on to the caesium surface in a vacuum photocell in the circuit shown.



The light energy falling each second on the caesium surface is 0.30 J.

(i) Show that the number of photons striking the caesium surface each second is approximately 6×10^{17}. [2]

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(ii) The current indicated by the ammeter is 0.80 µA. Calculate the number of electrons per second emitted from the caesium surface, stating your assumption. [3]

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(iii) Hence calculate the *probability* of a photon of this frequency ejecting an electron from a caesium surface. [1]

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