1. (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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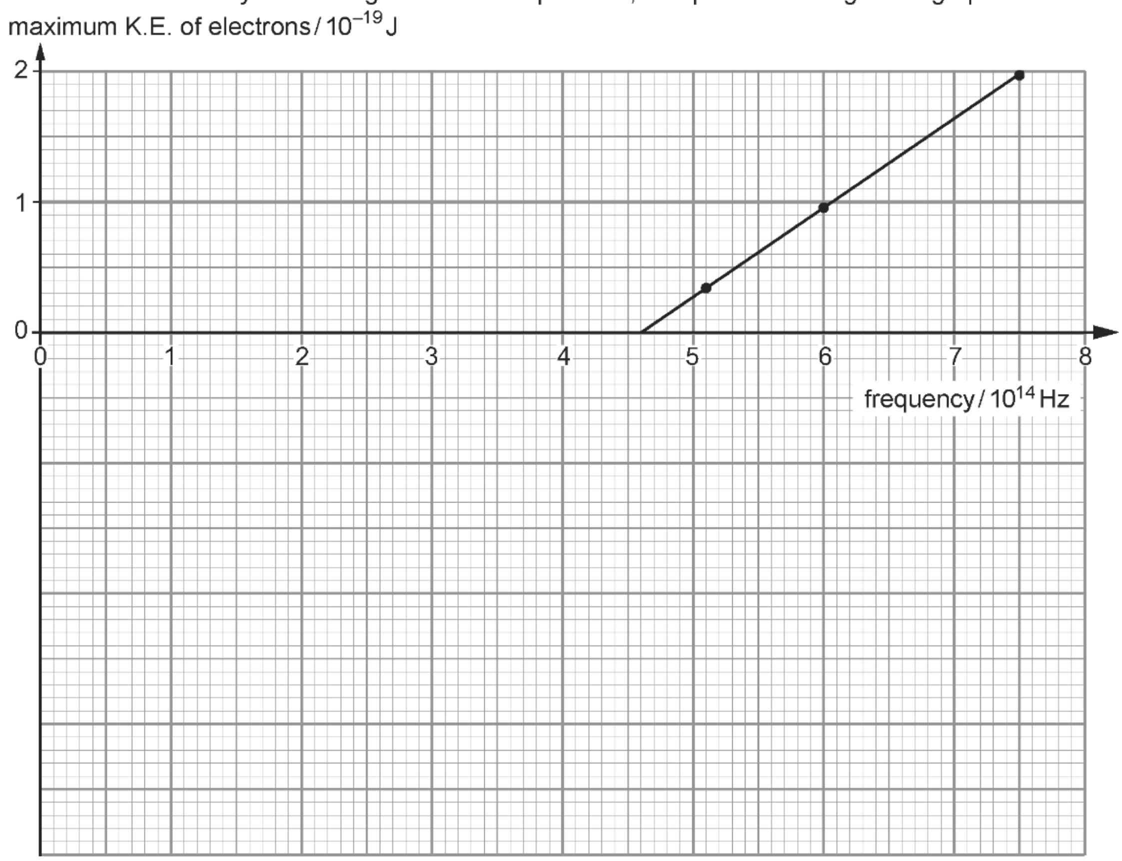
(c) A student determines the maximum kinetic energy of electrons ejected from a caesium surface by incident light of three frequencies, and plots the straight line graph shown.



(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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2.

(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]

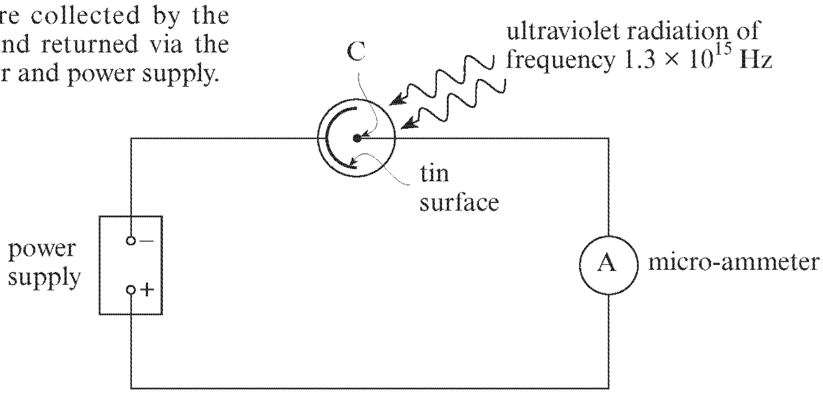
(b) The *work function* of tin is 7.1×10^{-19} J.

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

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

(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]

(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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3.

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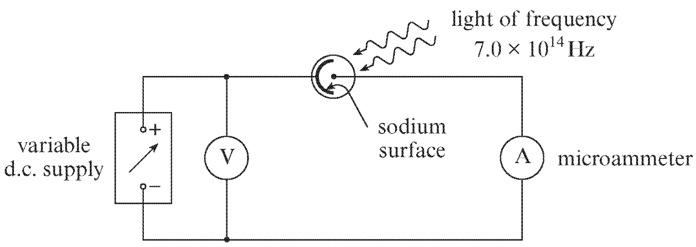
(d) The diagram shows apparatus set up to check experimentally the answer to *(b)*(ii). Describe how you would make this check. [4]



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4.

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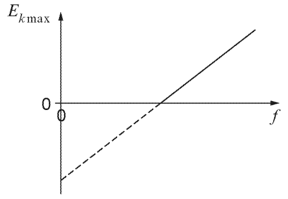
(d) The graph shows how the maximum kinetic energy, $E_{k\max}$ of electrons ejected from a magnesium surface varies with the frequency, f, of ultraviolet radiation falling on the surface.



State the physical quantities represented by:

(i) the gradient; [1]

....

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

....

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

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5.

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

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

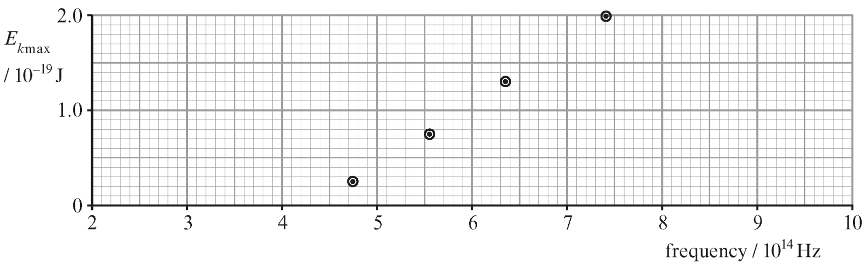
(i) $E_{k\max}$ .... [1]

(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]

....

(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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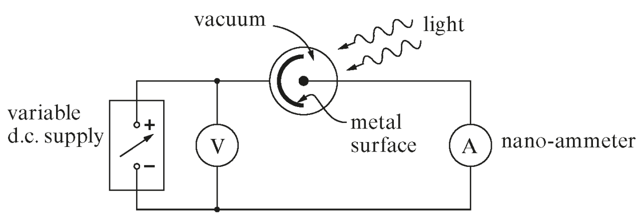
6.

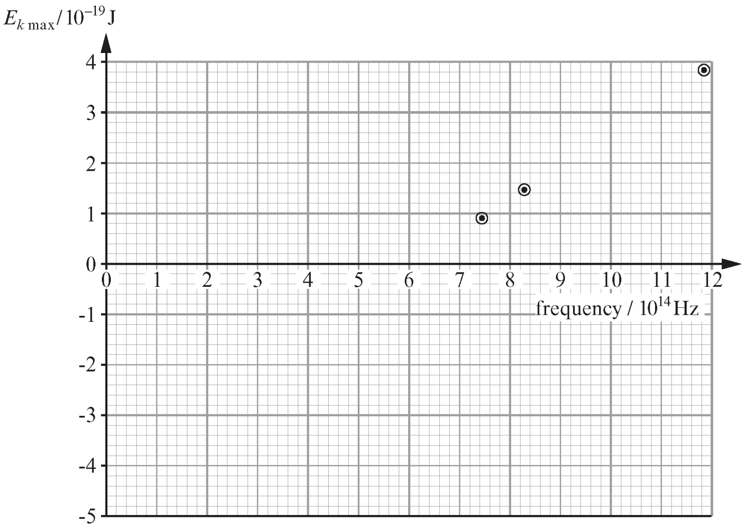
(a) (i) The threshold frequency for electrons to be emitted in the photoelectric effect is $f_0 = \frac{\phi}{h}$. Explain, in terms of energy, why this is so. [3]

(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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7.

(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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8. **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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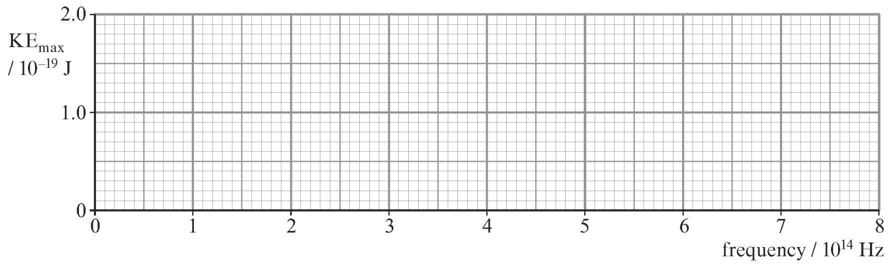
(c) (i) Making use of your answers to *(a)* and *(b)*(i), draw a graph, on the axes provided, to show how KE_{max} would depend on the frequency of incident light. [2]



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

....

(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]