ATOMS: PHOTONS AND THE PHOTOELECTRIC EFFECT QUESTIONS

SODIUM LAMPS (2012;2)

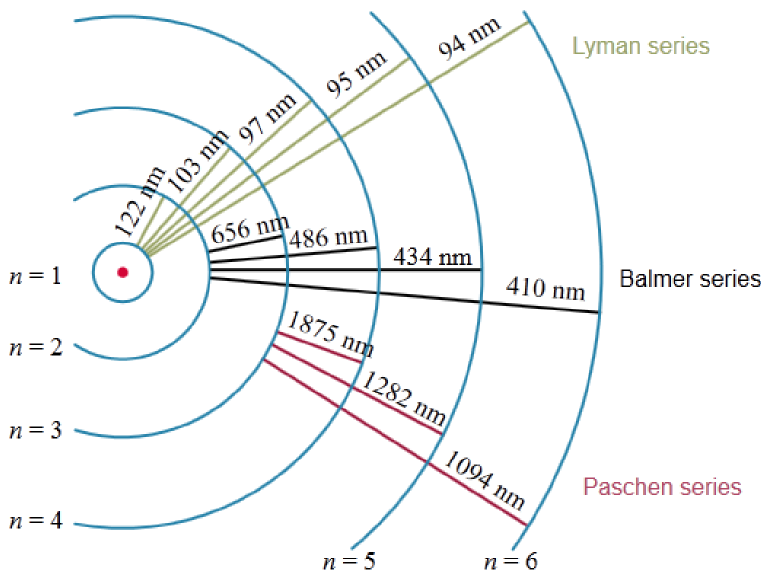
Low pressure sodium lamps are widely used in street lighting. The lamps produce light when an electric current is passed through sodium vapour. Almost all the light from these lamps has a wavelength of 5.89×10^{-7} m.

(a) Calculate the energy for a photon of light emitted from a sodium lamp.
(b) The work function for sodium is 2.28 eV. Calculate the threshold frequency for the emission of photoelectrons from the surface of sodium metal, and hence the maximum wavelength of light that can cause photoemission.
(c) Show that light from a sodium lamp cannot cause photoemission of electrons from sodium metal. By considering the energy transitions involved in light production and absorption, suggest a possible reason for this.

ATOMS AND PHOTONS (2011;2)

(a) State what a photon is, and describe how it can be produced by electrons within an atom.
(b) X-rays are used to take photographs of bones inside the body. X-ray photons typically have frequencies in the range 10^{16} Hz to 10^{19} Hz. An X-ray photon has energy of 191 eV. Calculate the frequency of the photon.
(c) When X-ray photons hit calcium, electrons are released. The frequency of a photon will have to be **more** than the threshold frequency if an electron is to be **released**. Discuss this statement in terms of the underlying physical principles.
(d) X-rays of frequency 1.53×10^{16} Hz cause the emission of electrons from a material with a maximum kinetic energy of 2.18×10^{-18} J. Calculate the threshold frequency for the release of electrons from the material.
(e) Explain why, if a photon causes an electron to jump to a higher energy level, the exact energy of the photon is critical, but if it is used to release an electron from the atom, it is only the minimum energy of the photon that is critical.

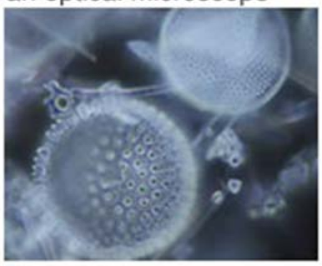
ATOMIC SPECTRA (2010;1)



(d) Light caused by a transition between the n = 2 and n = 1 levels is shone on to the surface of magnesium, causing emission of electrons. Magnesium has a work function of 3.66 eV. Calculate the maximum kinetic energy of the emitted electrons, in joules.

LIGHT AND ELECTRON MICROSCOPES (2010;2)

Image observed with an optical microscope



Specimen: Diatom
* Note that the diatom in these images observed with optical and electronic microscopes are not the same.

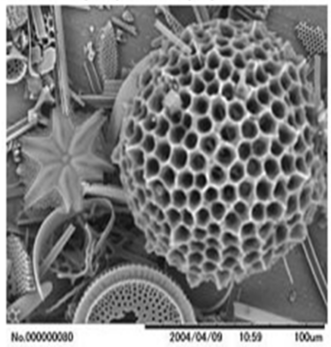
Most microscopes use light (photons) to form an image.

(a) The details seen with a light microscope are limited by diffraction. Light microscopes cannot image details that are smaller than the wavelength of the light which is being used. Calculate the size of the smallest details that can be seen with visible light photons of energy 4.97×10^{-19} J.

(b) Describe and explain one piece of experimental evidence which shows that light is not simply a wave, but that it also has a particle nature.

Some microscopes form an image using electrons rather than light. Electron microscopes illuminate the specimen with an "electron gun", rather than a lamp.

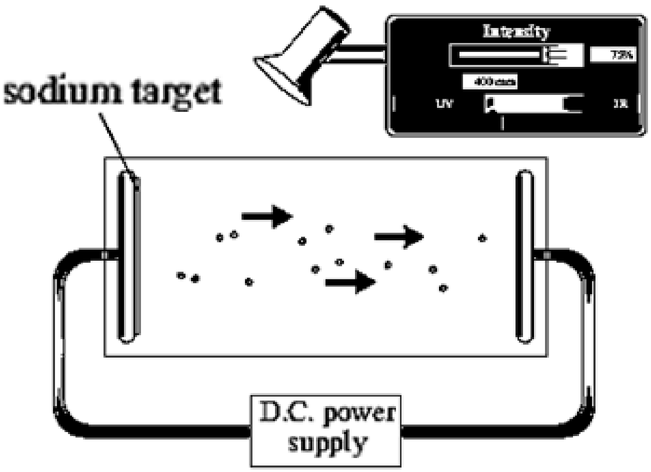
Images observed with an electronic microscope (Miniscope)



(c) In an electron microscope the electron gun accelerates electrons through a potential difference of 10 kV. Calculate the kinetic energy gained by an electron crossing this potential difference. State your answer in joules.

(d) When the electrons hit a sample, they may excite the atoms they hit and cause X-ray photons to be emitted. Calculate the minimum voltage needed in the electron gun to produce electrons with sufficient energy to cause emission of X-rays from oxygen atoms, with a wavelength of 2.36×10^{-9} m. State any assumptions you make.

THE PHOTOELECTRIC EFFECT (2009;2)



The diagram shows a simulation of the photoelectric effect. As violet light is shone on the sodium target, electrons leave the sodium and move to the right, causing a small current in the circuit.

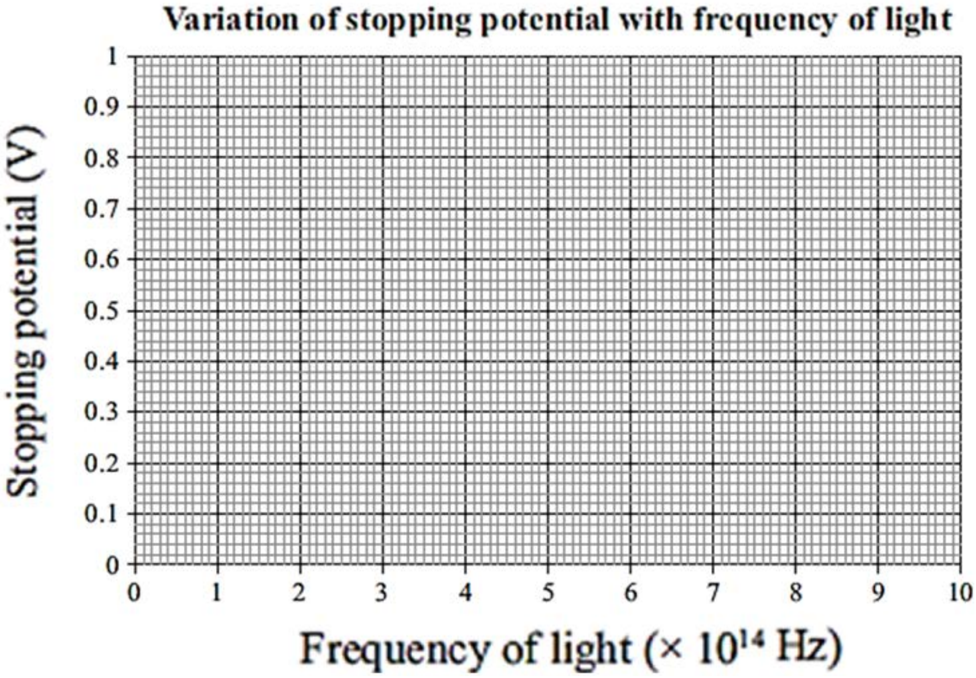
(a) When the wavelength of the light is increased, the light becomes red and no electrons leave the sodium. Explain why violet light, but not red light, causes electron emission.

(b) While violet light shines at the sodium, a student studies the effect of varying the intensity of the light. Describe and explain how this will affect the rate of electron emission, the maximum speed of the emitted electrons and the current in the circuit.

(c) With violet light of wavelength 4.00×10^{-7} m shining at the target, the D.C. power supply is changed until there is no current. This stopping potential is 0.80 V.

(i) Calculate the maximum kinetic energy (in joules) of the electrons leaving the surface of the sodium.

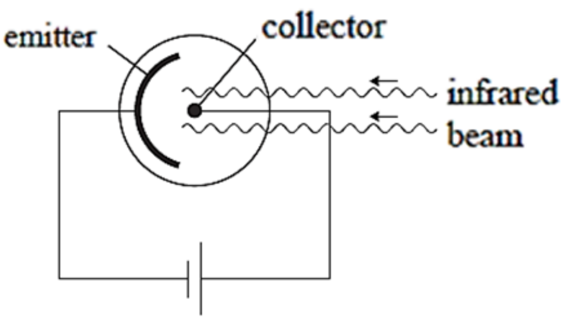
(ii) Calculate the threshold frequency for sodium. Use this value to draw a line on the graph which shows how stopping potential varies with the frequency of the light shone at the sodium surface. Clearly show your method for the calculation of all quantities.



PHOTOELECTRIC EFFECT (2008;3)

Planck's constant = 6.63×10^{-34} Js

One way in which automatic doors operate is to have a beam of infrared radiation directed on to a photocell. The beam is arranged so that it is broken if someone approaches the door and stops the radiation hitting the photocell. A simple model of the operation of the system is shown in the diagram below. A sensor sends a signal to the door opener when the current in the circuit stops.



The infrared radiation has frequency 1.32×10^{13} Hz.

(a) Calculate the energy of the infrared photons.

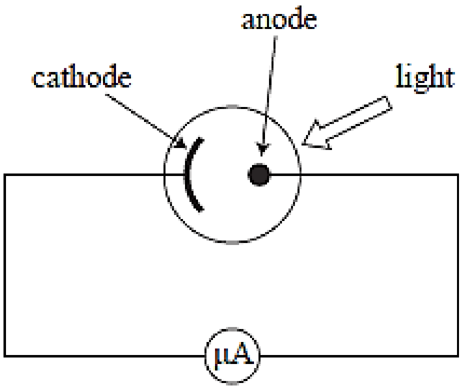
(b) Explain how the infrared photons cause current in the circuit.

(c) One of the materials considered for the emitter plate has a work function energy of 8.94×10^{-21} J. Explain whether this material would be suitable.

(d) The material that is finally chosen for the emitter plate has a threshold frequency of 9.85×10^{12} Hz. Calculate the maximum energy of the photoelectrons released.

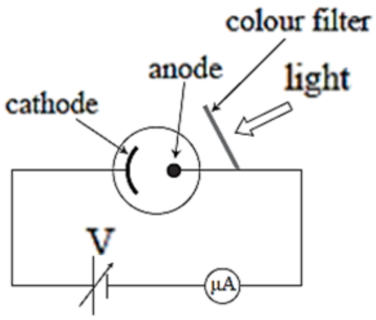
PHOTOELECTRIC EFFECT (2007;3)

Speed of light	$= 3.00 \times 10^{8}$ m s^{-1}
Charge on the electron	$= 1.6 \times 10^{-19}$ C
Planck's Constant	$= 6.63 \times 10^{-34}$ J s



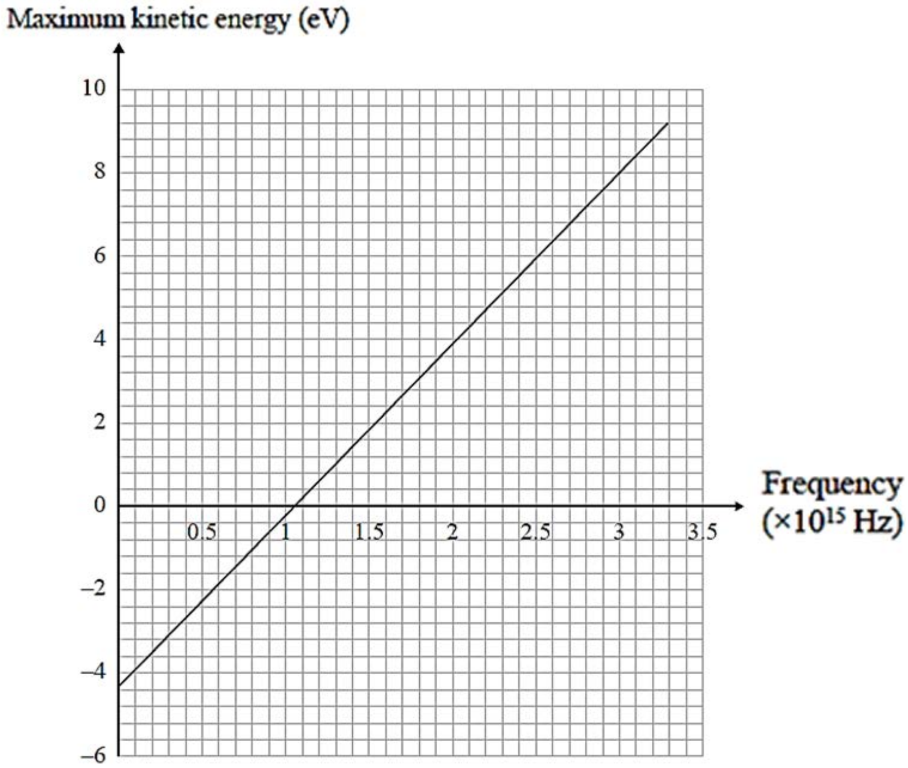
Historically, photographers have used light meters containing photocells that are modelled on the photoelectric effect.
A photocell consists of a vacuum tube containing a curved sheet of zinc metal as the cathode and a metal pin as the anode, as shown in the diagram below. When light shines on the photocell, there is a current in the circuit. A very sensitive meter measures this current.

(a) Describe what causes a current in the circuit.
(b) Explain how changing the brightness of the light affects the size of the current in the circuit.



To investigate the properties of the photocell, a variable voltage supply is connected to the photocell, as shown in the circuit diagram. Using a colour filter makes the light hitting the zinc cathode monochromatic.

The voltage is changed until there is no current in the circuit. This voltage is a measure of the maximum kinetic energy of the released electrons, in electron volts.
By using different colour filters to change the frequency of the light hitting the zinc cathode, a graph of maximum electron kinetic energy, in electron volts, against frequency is drawn.



(c) From the graph, determine the threshold frequency of zinc.

(d) The equation for the maximum kinetic energy of the released electrons, in joules, is

$$E_K = hf - \phi .$$

Using information from the graph, calculate a value for Planck's constant. Show your working.

(e) Determine the threshold frequency for a metal that releases an electron with maximum kinetic energy of 3.94×10^{-20} J when light of wavelength 4.01×10^{-7} m shines on it.

NIGHT VISION CAMERA (2006;3)

Planck's constant = 6.63×10^{-34} Js

A night vision camera detects low levels of light on the photo-cathode, which releases a few electrons. A photomultiplier increases the number of electrons, which then hit the screen to produce an image.

(a) Name the effect that causes electrons to be released by the photo-cathode.
(b) The photo-cathode material of this night vision camera prevents it detecting infrared radiation. State why this is so.

The photo-cathode is made of a material that has a work function of 2.58×10^{-19} J.

(c) Calculate the lowest frequency of light that could release a photoelectron.
(d) Explain the effect on the number and energy of the electrons released when the frequency of the light is decreased.

The photo-cathode is replaced with a different material. When illuminated with light of wavelength 2.80×10^{-7} m, electrons with a maximum kinetic energy of 3.04×10^{-19} J are produced.

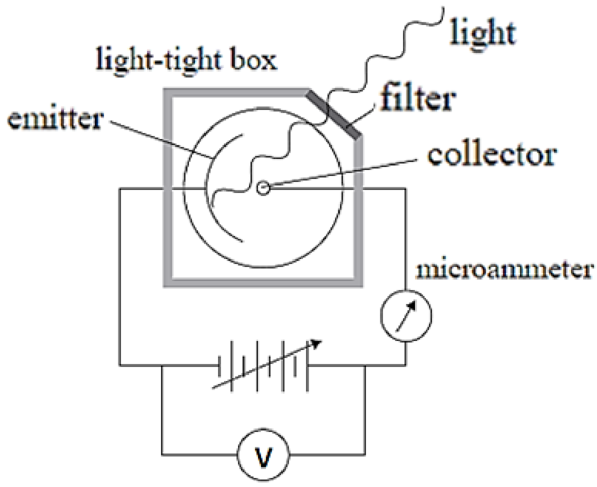
(e) Calculate the threshold frequency for the material.

LIGHT ENERGY CHANGED TO ELECTRICAL ENERGY (2005;1)

$$\text{Charge on an electron} = 1.60 \times 10^{-19}\ \text{C}$$
$$\text{Speed of light} = 3.00 \times 10^{8}\ \text{m s}^{-1}$$
$$\text{Planck's constant} = 6.63 \times 10^{-34}\ \text{J s}$$
$$\text{Rydberg's constant} = 1.10 \times 10^{7}\ \text{m}^{-1}$$

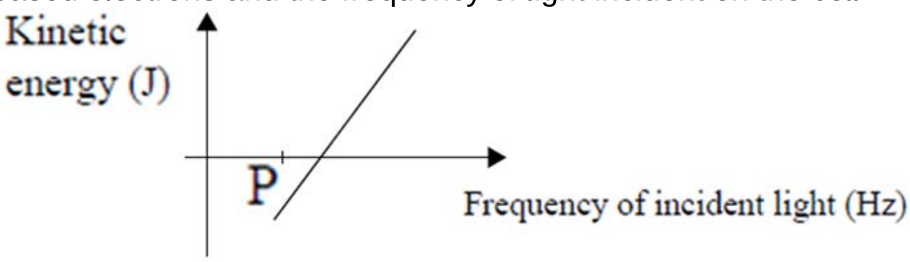
Year 13 photography students were taking photographs of Prince William on his recent visit to New Zealand. The camera they were using had a light meter that measured the brightness of the light. One of the students mentioned that the light meter was developed from the photoelectric cell. In a photoelectric cell, electrons are released to generate a current when light is incident on the metal surface of the cell. The circuit diagram of a cell is shown.

light meter



(a) Light of frequency 6.16 x 10^{14} Hz is incident on the photoelectric cell. Calculate the energy of the light photons.

Each photon will release an electron. The graph below shows the relationship between the kinetic energy of the released electrons and the frequency of light incident on the cell.



(b) Describe what would happen if light of frequency P were incident on the photoelectric cell.

(c) Each photon of frequency 6.16 x 10^{14} Hz will release an electron with a maximum kinetic energy of 0.35 eV. Calculate the threshold frequency of the metal surface of the cell.

(d) If the metal of the photoelectric cell is now changed to one with a greater work function, draw a line on the graph above to represent how its kinetic energy would depend on the frequency of the incident light.

(e) Explain what effect the brightness of the light will have on the current generated in the photoelectric cell.

If the battery is reversed, its voltage can be adjusted until the current stops.

(f) Explain how this cut-off (stopping) voltage, when the light is brighter, compares with the cut-off voltage when the light is less bright.

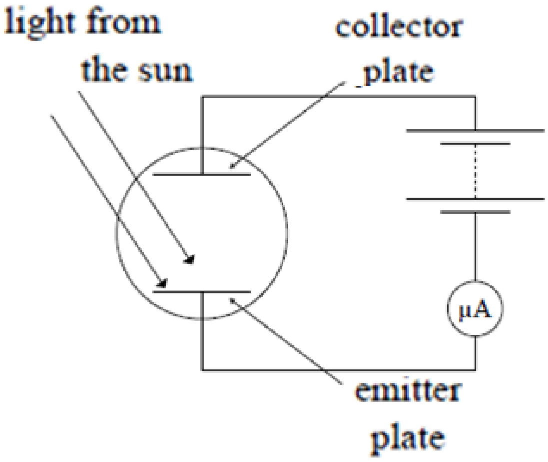
(g) State TWO different ways in which the wave model of light fails to explain the photoelectric effect. Explain ONE of the statements you make.

QUESTION THREE (2004;3)

Use the following information when answering this question:

$$\text{Speed of light} = 3.00 \times 10^{8}\ \text{m s}^{-1}$$
$$\text{Planck's constant} = 6.63 \times 10^{-34}\ \text{J s}$$

Light energy from the Sun can be changed into electrical energy by a photoelectric cell. The diagram shows an experimental set-up that can be used to investigate this energy change. The emitter plate has work function energy of 3.0 x 10^{-19} J.



(a) State why it is necessary to make the collector plate positive.
(b) Explain why the sun's light energy can cause a current in this circuit.
(c) Calculate the maximum wavelength of light that will cause a current.

Level 3 Physics: Atoms – The Photoelectric Effect - Answers

In 2013, **AS 91525** replaced **AS 90522.** Prior to 2013, this was an external standard - AS90522 Atoms, Photons and Nuclei.
It is likely to be assessed using an internal test from 2013 onwards (although teachers can select from a range of assessment techniques). There were only minor changes to this existing material in the standard when it became AS91525 but also a number of additions including Relativity and some material on fundamental particles. The old external examinations may be useful revision for an internal test.

However, the mess that is NCEA Assessment Schedules….

In 90522 there was an Evidence column with the correct answer and Achieved, Merit and Excellence columns explaining the required level of performance to get that grade. Each part of the question (row in the Assessment Schedule) contributed a single grade in either Criteria 1 (Explain stuff) or Criteria 2 (Solve stuff). From 2003 to 2008, the NCEA shaded columns that were not relevant to that question (Sorry haven't had time to do 2004 yet).

Question	Evidence	Achievement	Merit	Excellence
2012(2) (a)	$E = \mathrm{h}f = \frac{\mathrm{hc}}{\lambda}$ $= 6.63\times10^{-34}\times\frac{3.0\times10^{8}}{5.89\times10^{-7}} = 3.38\times10^{-19}\ \mathrm{J}$	[2] Correct working for frequency ($f = 5.09\times10^{14}$ Hz) OR Correct answer without any working	[2] Correct answer with some working.	
(b)	$\mathrm{h}f = \phi + E_{\mathrm{K}}$ at the threshold frequency $\mathrm{h}f = \phi = 2.28\ \mathrm{eV} = 2.28\times1.6\times10^{-19} = 3.648\times10^{-19}\ \mathrm{J}$ $f = \frac{\phi}{\mathrm{h}} = \frac{3.648\times1.6\times10^{-19}}{6.63\times10^{-34}} = 5.50\times10^{14}\ \mathrm{Hz}$ $\lambda = \frac{\mathrm{c}}{f} = \frac{3.0\times10^{8}}{5.50\times10^{14}} = 5.45\times10^{-7}\ \mathrm{m}$	[2] Correct conversion of eV into J. (3.648×10^{-19} J) OR [1] Indication that $E_{\mathrm{K}} = 0$. OR Indication that $\varphi = hf$.	[2] Correct working and answer for threshold frequency ($f = 5.50\times10^{14}$Hz). OR Correct working for wavelength, but with incorrect or missing conversion of workfunction (8.72×10^{-26} if left as 2.28eV). OR Correct working with minor error, eg ONE wrong rearranging.	[2] Correct answer showing sufficient working. NOTE: E_{K} cannot be non-zero.

(c)	*Show that light from a sodium lamp cannot cause photoemission of electrons from sodium metal.* The wavelength of light needed to release electrons (545nm) smaller than the 589nm light emitted by the sodium light. This means the energy provided by a photon from the sodium lamp doesn't have enough energy to overcome the work function of the sodium metal and so no electrons will be released. *By considering the energy transitions involved in light production and absorption, suggest a possible reason for this.* Light from the sodium lamp is produced by electrons moving from higher energy levels to lower energy levels, losing this energy as a photon. The photon of wavelength 589nm corresponds to the energy difference between two energy levels in the sodium atom. These two energy levels, therefore, are too close together to allow the emitted photon to have enough energy to release an electron from the sodium metal.	[1] Wavelength needed for release is LESS than sodium line OR Frequency needed for release is HIGHER than sodium line OR Energy is less than work function / energy needed to release electron OR Minimum energy of light needed to overcome work function / release electron	[1] Compares energy of the **photon** to the work function / energy needed to release OR Difference in energy levels in (gaseous) sodium **too small** to overcome work function	[1] Compares energy of the **photon** to the work function / energy needed to release AND Difference in energy levels in (gaseous) sodium **too small** to overcome work function)
2011(2) (b)	$J = e \times \text{eV} = 1.60\times10^{-19} \times 191$ $= 3.056 \times 10^{-17}$ J $E = hf \Rightarrow f = \dfrac{3.056\times10^{-17}}{6.63\times10^{-34}}$ $= 4.60935 \times 10^{16}$ Hz $= 4.61 \times 10^{16}$ Hz (3sf)	[2] Correct method using incorrect energy value (eg not converted to Joules, $f = 2.88 \times 10^{35}$).	[2] Correct answer and working. *Allow rounding errors in working.*	

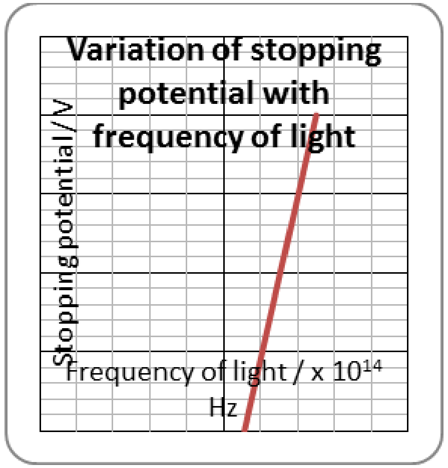
(c)	To release an electron, it must first gain enough energy to overcome the attraction of the positive nuclei in the metal. This minimum amount of energy is called the work function of that particular metal. When one photon interacts with one electron, the photon's energy is absorbed by the electron. If the photon's energy is LARGER than the work function, the electron has gained enough energy to overcome the attraction to the positive nuclei and escape the metal. Any energy above that to escape the metal will contribute to the electron's kinetic energy. Since the energy of a photon is directly proportional to its frequency, the larger the frequency the larger the energy of the photon. Therefore, for the photon to pass on enough energy to electron in order to be released, the photon must have a minimum frequency. This frequency is called the threshold frequency.	[1] Minimum/enough Energy required/ excited enough to release electron/ required to overcome work function/to be raised to its free energy state – this **Must** be stated – not simply implied (accept "photon must have energy higher than *something* to release electron") (Do **not** accept "photon must overcome the threshold frequency") OR Electron absorbs/gains photon's energy/ photon transfers/gives/provides energy to the electron OR Energy of a photon depends on frequency (larger f => larger E) beyond a simple statement of the formula E = hf	[1] Mentions TWO of —Minimum / enough Energy required / excited enough to release electron / required to overcome work function / to be raised to its free energy state – this MUST be stated – not simply implied. ("Photon must have energy higher than *something* to release electron" accepted.) ("Photon must overcome the threshold frequency" not accepted.) OR Electron absorbs / gains photon's energy / photon transfers/gives / provides energy to the electron OR Energy of a photon depends on frequency (larger f => larger E) beyond a simple statement of the formula E = hf.	Links all THREE: Minimum/enough Energy required/ excited enough to release electron/ required to overcome work function/to be raised to its free energy state – this **must** be stated – not simply implied. ("Photon must have energy higher than *something* to release electron" accepted.) ("Photon must overcome the threshold frequency" not accepted.) OR Electron absorbs / gains photon's energy / photon transfers / gives / provides energy to the electron OR Energy of a photon depends on frequency (larger f => larger E) beyond a simple statement of the formula E = hf AND causally linked to threshold frequency, eg: therefore there exists a threshold frequency.
(d)	$hf = \phi + E_K$ $\phi = hf - E_K$ $\phi = (6.63 \times 10^{-34} \times 1.53 \times 10^{16}) - 2.18 \times 10^{-18}$ $\phi = 1.01439 \times 10^{-17} - 2.18 \times 10^{-18}$ $\phi = 7.96 \times 10^{-18}$ $f_{threshold} = \frac{\varphi}{h} = \frac{7.96 \times 10^{-18}}{6.63 \times 10^{-34}} = 1.20 \times 10^{16}$ Hz (3sf)	[2] Correctly substitutes into hf = $\phi + E_K$ (Allow correct substitution into incorrectly rearranged formula) OR Attempts to combine both formulae.	[2] Correct value and working for ϕ.	[2] Correct answer and working.

(e)	When an electron interacts with a photon, the electron absorbs all of the photon's energy. The electron inside the atom of a low density gas can only occupy specific energy levels. In order to lift the electron to a higher energy level, the energy of the photon must provide exactly the difference in energy between the levels. If the energy of the photon does not match any of the energy level transitions, the electron will not absorb the photon. Therefore the exact energy is crucial in whether a photon is absorbed or not. If the energy of the photon is large enough, then it can release the electron from the atom, overcoming the electron's attraction to the nucleus. Once freed, any excess energy is converted to the kinetic energy of the electron which can have any value. Therefore any value above that needed to release the electron from the atom can be absorbed by the electron.	[1] ONE of: • idea of quantised energy levels of electron, (eg discrete / fixed / specific / different energy levels) OR specific / discrete / only some allowed differences in energy levels. • electron absorbs / gains the **photon's** energy / photon gives / provides/ transfers energy to electron. • Energy is needed to overcome the work function/attraction of the nucleus/be lifted to its free state. • Energy above minimum for release will also release electrons / any energy above minimum is converted to the kinetic energy of the electron.	[1] EITHER (a) Specific (exact) energy of the **photon** needed to move electron up **because** of **specific** (fixed / discrete / quantise / different) **energy levels** (**not** orbits / shells etc.). OR (b) Reason provided why minimum energy for release needed (eg to overcome work funtion, to raise to free state, to provide ionisation energy etc.). AND ONE of • idea of quantised energy levels • energy of photon must equal energy difference between levels.	[1] Statement (a) AND Statement (b) AND ONE of • energy above minimum release energy goes into kinetic energy of the electron. • energy of photon must equal energy difference between levels.

2010(1) (d)	$\frac{1}{\lambda} = 1.097 \times 10^7 \left(\frac{1}{1^2} - \frac{1}{1^2}\right) = 8.2275 \times 10^6$ Or uses value given, 122 nm $E = hf = \frac{hc}{\lambda}$ $= 6.626 \times 10^{-34} \times 3.00 \times 10^8 \times 8.2275 \times 10^6$ $= 1.635 \times 10^{-18}$ J $hf = \phi + E_K$ $E_K = hf - \phi$ $E_K = (1.635 \times 10^{-18}) - (3.66 \times 1.6 \times 10^{-19})$ $E_K = 1.04 \times 1.6 \times 10^{-18}$ J Or uses values given,122 nm $E = hf = \frac{hc}{\lambda}$ $= \frac{6.626 \times 10^{-34} \times 3.00 \times 10^8}{1.22 \times 10^{-9}}$ $= 1.629 \times 10^{-18}$ J $hf = \phi + E_K$ $E_K = hf - \phi$ $E_K = (1.629 \times 10^{-18}) - (3.66 \times 1.6 \times 10^{-19})$ $E_K = 1.04 \times 10^{-18}$ J Also accept 1.05×10^{-18} J	2 Converts ϕ into J $3.66 \times 1.6 \times 10^{-19}$ $= 5.86 \times 10^{-19}$ J OR frequency calculated correctly. $f = 2.47 \times 10^{15}$ Hz	2 Correct calculation of photon energy. $= 1.635 \times 10^{-18}$ J Or in eV = 10 eV	2 Complete answer. $= 1.04 \times 10^{-18}$ J $= 1.05 \times 10^{-18}$ J
2010(2) (a)	$E = hf = \frac{hc}{\lambda}$ $\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^8}{4.97 \times 10^{-19}}$ $\lambda = 4.00 \times 10^{-7}$ m	2 Correct frequency of $E = hf$ $f = \frac{E}{h}$ $= \frac{4.97 \times 10^{-19}}{6.626 \times 10^{-34}}$ $= 7.5 \times 10^{14}$ Hz	2 400 nm $= 4.00 \times 10^{-7}$ m	

(b)	Photo electric effect: Threshold frequency – there is no emission of electrons when the surface is illuminated with light below a threshold frequency, however intense this light is. This suggests that the light is interacting with the surface in discrete amounts of energy. If the energy of this photon is too low then no electron emission can occur. Photo electric effect: No time delay at low light intensity. There is no evidence the energy is spread out at low energies because electron emission begins immediately. This agrees with a 1 photon = 1 electron emission model. Blackbody radiation answers are also acceptable.	Mentions photoelectric effect OR loosely describes Photoelectric effect.	[1] Mentions threshold frequency or no time delay in photo electric effect.	[1] Complete answer explaining either why threshold frequency or no time delay means that light energy is quantised.
(c)	$E_K = eV = 1.6 \times 10^{-19} \times 10 \times 10^3$ $= 1.6 \times 10^{-15}$ J	[2] Correct answer.		
(d)	$E_{photon} = hf = \frac{hc}{\lambda}$ $= \frac{6.626 \times 10^{-34} \times 3.00 \times 10^8}{2.36 \times 10^{-9}} = 8.423 \times 10^{-17}$ $V = \frac{E_k}{e} = \frac{8.423 \times 10^{-17}}{1.6 \times 10^{-19}} = 526$ V The electrons must have energy equal to (or greater than) that of the photon (all the electron energy can be released as a photon).	[2] Frequency calculated correctly. $f = 1.27 \times 10^{17}$ Hz [1] Correct assumption. Do not accept work function is negligible or conservation of energy.	[2] Calculation of photon energy. $= 8.423 \times 10^{-17}$ J	[2] Correct answer. 526 V or 527 V

2009(2) (a)	Red light photons have low frequency so low energy; therefore they don't have enough energy to release electrons. Violet light has higher frequency so higher energy photons, they give the electrons enough energy to leave the surface of the sodium OR Red light frequency is less than the threshold frequency, so electrons do not have enough energy to escape. Violet photons have more energy, so they have enough to let electrons escape. OR The electrons in sodium have a work function which is a minimum amount of energy required for them to leave the surface. The photons of light must provide this energy or else the electron can't escape. Red light photons have energy less that the work function and violet light photons have a greater energy than the work function.	[1] Indicates understanding that there is a minimum energy from photons / quanta of radiation causes emission of electrons OR energy of red photons is less than that of violet. OR idea that there is a minimum frequency for electron emission and red light is below the threshold frequency.	[1][Links energy of light to frequency or wavelength OR good understanding of photons] AND [Compares violet light energy and red light energy OR links to increasing wavelength] AND Enough/not enough energy to [cause electrons to be emitted OR overcome work function] Has to have link between energy and emission.	
(b)	As the intensity increases, more photons are hitting the target each second, causing more electron emissions per second and hence more in the circuit and a larger current. The light is still violet, so the frequency and **energy** of the photons is not changed, (so each electron gets the same energy as before). Therefore the speed of the emitted electrons will not be changed. (This explanation needs - speed of electron, not just energy of the electron, AND energy of the photons, not just frequency)	[1]One effect described with no incorrect effects OR Two effects described with one incorrect effect OR One effect described and explained (with incorrect effect/s)	[1]One effect described and explained OR all three effects described but not explained. To get merit there must be no incorrect effects (e.g. electrons are faster)	[1]Complete answer. All correct plus has clearly linked to increased (or decreased) intensity
(c)(i)	At the stopping potential, $eV = E_K$ $E_K = 1.6 \times 10^{-19} \times 0.8 = 1.28 \times 10^{-19}$ $= 1.3 \times 10^{-19}$ J		[2]Correct answer with working.	

(c)(ii)	$f_{violet} = \frac{v}{\lambda} = \frac{3\times10^{8}}{4.0\times10^{-7}} = 7.5\times10^{14}\,Hz$ $hf = \phi + E_K$ $\phi = hf - E_K$ $= 7.5\times10^{14}\times6.63\times10^{-34} - 1.28\times10^{-19}$ $= 3.6925\times10^{-19}\,J$ (from c(i)) $f_{threshold} = \frac{\phi}{h} = \frac{3.6925\times10^{-19}}{6.63\times10^{-34}} = 5.56938\times10^{14}$ $= 5.6\times10^{14}\,Hz$ Graph connects points (5.6,0) and (7.5,0.8) which is the point for violet light. 	2 Correct calculation of frequency of violet light and correct shape of graph (straight line with positive slope that cuts the x-axis) Note: Frequency of violet light could be found in c(i) OR Correct work function calculated.	2 Correct calculation of the threshold frequency.	2 Correct threshold frequency with correct working and correct graph.
2008(3) (a)	E = hf = 6.63 × 10^{-34} × 1.32 × 10^{13} = 8.7516 × 10^{-21} **= 8.75 × 10^{-21} J**	2 Correct answer.		

(b)	Photons cause emission of electrons from the emitter. Electrons travel to the collector and hence a current in the circuit.	[1]One point clear.	[1] Both points linked, demonstrating understanding.	
(c)	For electrons to be released, the energy of the photon must be greater than the work function energy. As this material has work function energy greater than the photon energy, it is not suitable. If answer to (a) $\geq 8.94\times10^{-21} J$, answer should be yes, suitable, etc.	[1]One key idea identified.	[1]Key ideas identified and linked are: Electrons released only if photon energy > work function energy. Material's work function energy is too high for electron release.	
(d)	$E_{electron} = E_{photon} - E_{work\ function}$ $E_{work\ function} = hf_o$ $= 6.63 \times 10^{-34} \times 9.85 \times 10^{12}$ $= \mathbf{6.53055 \times 10^{-21}}$ $\Rightarrow E_{el} = 8.7516 \times 10^{-21} - 6.53055 \times 10^{-21}$ $= 2.22105 \times 10^{-21}$ $= \mathbf{2.22 \times 10^{-21}\ J}$ OR $E_k = h(f - f_0)$ $= 6.63 \times 10^{-34} (1.32 \times 10^{13} - 9.85 \times 10^{12})$ $= \mathbf{2.22 \times 10^{-21}\ J}$	[2]Correct work function energy.	[2]Correct answer.	
2007(3) (a)	Electrons are released when light shines on the metal.	[1]Correct idea. (Light releases electrons from anode is incorrect – but allow photons release electrons from anode.)		
(b)	Changing the brightness of the light changes the number of photons hitting the metal per second. As each photon can release only one electron, as the brightness increases, more electrons are released per second. The greater rate of flow of electrons means a greater current is flowing.	[1]Brighter light linked to either more photons or more electrons. (accept Changing brightness increases number of electrons.)	[1]Brighter light linked to more photons and hence more electrons.	

(c)	Frequency intercept = 1.05×10^{15} Hz	[2]Correct answer (must include $\times 10^{15}$, do not allow 1 or 1.1)		
(d)	$E_K = hf - \phi \Rightarrow$ gradient of the graph is h provided E_K is changed to joules. $\Rightarrow h = \dfrac{(8.0-0)\times 1.6\times 10^{-19}}{(3.00-1.05)\times 10^{15}}$ $= 6.5641 \times 10^{-34}$ **=** 6.6×10^{-34}	[2]Correct answer without changing eV to joule OR conversion to Joules incorrect. Calculation shows understanding of how to obtain Plancks' constant from the graph.	[2]Correct answer consistent with data from graph	
(e)	$\phi = hf_o$, and $\phi = hf - E_K$ and $c = f\lambda$ $\Rightarrow f = \dfrac{3.00\times 10^{8}}{4.01\times 10^{-7}} = 7.48130 \times 10^{14}$ Hz $\Rightarrow \phi = 6.63\times10^{-34} \times 7.48130 \times 10^{14} - 3.94\times10^{-20}$ $= 4.56610 \times 10^{-19}$ J $\Rightarrow f_o = \dfrac{4.56610\times 10^{-19}}{6.63\times 10^{-34}}$ $= 6.88703 \times 10^{14} = 6.89 \times 10^{14}$ Hz	[1]A correct answer implies knowledge of concepts.	[2]Correct answer consistent with incorrectly calculated frequency or work function.	[2] Correct answer
2006(3) (a)	Photoelectric effect	[1]Correct answer.		
(b)	Photons of IR light have frequency / energy too low to release photoelectrons/below threshold frequency/ lower than work function.	[1]Correct answer.		
(c)	Energy of photon must be 2.58×10^{-19} J $E = hf \quad \Rightarrow f = \dfrac{2.58\times 10^{-19}}{6.63\times 10^{-34}}$ $= 3.8914 \times 10^{14}$ $= 3.89 \times 10^{14}$ Hz	[2]Correct answer.		

(d)	Each photon is able to release one electron. The frequency of the photons determines the energy of the electrons released. An electron needs a minimum amount of energy to be released and so below a threshold frequency no electrons are released. Above this frequency the energy of each electron is whatever is left after the release energy has been used. Therefore as the frequency is decreased the energy of the electrons released decreases. The number of electrons released does not change as the number of photons is the same, given that the intensity is the same. Below the threshold frequency no electrons are released.	[1]Decreasing frequency means decreasing electron energy / decreasing frequency does not change the number of electrons/ lower frequency below threshold frequency so no electrons.	[1]Link between decreasing frequency and decreasing energy is explained in terms of $E_k = hf - \phi$ / link between decreasing frequency and same number of electrons explained in terms of photon numbers.	[1]Explanation correctly links the observation of changes in electron energy and numbers as frequency decreases to photon nature of light and work function, including threshold frequency.
(e)	$E_{photon} = hf$ and $c = f\lambda \Rightarrow E_{photon} = \frac{hc}{\lambda}$ $E_{photon} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{280 \times 10^{-9}}$ $= 7.104 \times 10^{-19}$ J $E_{electron} = 3.04 \times 10^{-19}$ J $E_{photon} = E_{electron} + E_{work\ function}$ $\Rightarrow E_{\phi} = 7.104 \times 10^{-19} - 3.04 \times 10^{-19}$ $= 4.064 \times 10^{-19}$ J $E_{work\ function} = E_{photon}(\text{min}) = h \times f_{min}$ $f_{min} = \frac{4.064 \times 10^{-19}}{6.63 \times 10^{-34}}$ $= 6.13 \times 10^{14}$ Hz		[2]Correct photon energy or correct answer consistent with either incorrectly calculated photon energy or incorrectly calculated work function energy.	[2]Correct answer.
2005(1) (a)	$E = hf$ $E = 6.63 \times 10^{-34} \times 6.16 \times 10^{14}$ $E = 4.08408 \times 10^{-19}$ J	[2] Correct answer.		
(b)	No electrons are emitted / nothing would happen / Photons energy is changed to heat.	Correct statement.		

(c)	$E_K = 0.35 \times 1.6 \times 10^{-19} = 5.6 \times 10^{-20}$ J $\phi = 4.08 \times 10^{-19} - 5.6 \times 10^{-20}$ $= 3.52 \times 10^{-19}$ J $f = \frac{\phi}{h}$ $= \frac{3.52 \times 10^{-19}}{6.63 \times 10^{-34}}$ $= 5.309 \times 10^{14}$ $= \mathbf{5.3 \times 10^{14}\ Hz}$	Correct calculation of E_K in joules.	Correct f consistent with incorrect E_K /correct work function.	Correct answer.
(d)	Graph line is parallel to the one shown but displaced to the right.	Correct graph line.		
(e)	In brighter light there will be more photons hitting the metal per second. As each photon releases an electron, more electrons will be released each second, hence greater current. OR – the light frequency is now below the threshold frequency and so no electrons are released regardless of brightness.	ONE correct and relevant statement: Brighter light means more photons / more photons so greater current/ brighter light means more electrons **AND** more current.	Link made between brighter light having more **photons**, and more photons emitting more electrons. **OR** below f_0 no electrons as not enough energy per photon to release electrons regardless of brightness.	In addition candidate refers to rate of photons hitting / rate of electrons being released
(f)	The cut-off voltage is a measure of the maximum kinetic energy of the emitted electrons in electron volts. Although there are more photons and hence more electrons released, each photon will release an electron with the same maximum KE. The cut-off voltage will therefore remain the same.	ONE correct and relevant statement: cut-off voltage depends on max KE of electrons / max KE of electrons stays the same even though brightness changes / no change in cut- off voltage.	Link made between cut-off voltage depending on KE of electrons, and brightness not affecting KE of electrons.	Explanation is clear, concise and accurate – clear understanding of voltage as energy per charge or as a measure of electron max KE.

(g)	According to the wave model, the brighter the light the greater the energy it carries. This suggests that a brighter light should release electrons with greater KE. In practice the energy of released electrons is independent of the brightness of the light. According to the wave model, frequency is independent of the energy of the wave and so all frequencies should release electrons with the same amount of energy. In practice, the energy of released electrons depends on the frequency of the light. As energy in a light wave is delivered in a smooth continuous way, it should take some time for electrons to be emitted. In practice electrons are emitted instantaneously.	ONE behaviour that is not predicted by the wave model is given.	TWO behaviours that are not predicted by the wave model are given. For ONE, the predicted behaviour is given.	