**Solutions**

**Example 1 2010 Question 5, 65%**

Increased intensity means more photons, but each photon still has the same energy. As the photons have the same energy, the max KE of the electrons (gained from the incoming photon) will remain the same. Therefore the graphs will be identical.

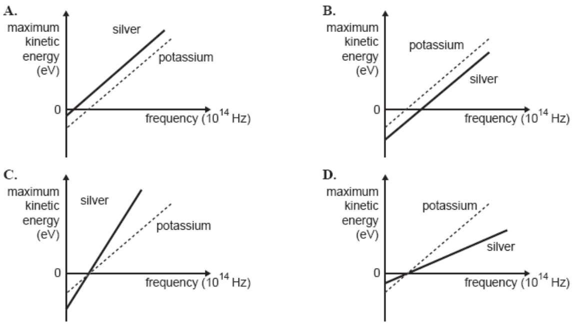
**D (ANS).**

**Example 2 2010 Question 6, 67%**

The work function is given by the Y-intercept. The lower work function of magnesium will give a higher graph. The gradient of the graph needs to remain constant, as it is Planck's constant.

**A (ANS)**

**Example 3 2006 Question 4, 65%**




The gradient of the lines had to be the same. They both give Planck's constant. If the work function for silver is higher, then the graph for silver needs to have a more negative 'y-intersect' value. Alternatively it will take more energy to release an electron, and so the cut-off frequency will be higher.

$\therefore$ **B (ANS)**

**Example 4 2004 Question 3, 67%**

Current only depends on intensity given that there is some.

$\therefore$ **A (ANS)**

**Example 5 2000 Question 6, 10%**

In order to do this question you must calculate the energy of a photon at 900nm, and make sure it is larger than the work function.

$$E = hf$$

$$E = 4.14 \times 10^{-15} \times \frac{3.0 \times 10^{8}}{900 \times 10^{-9}}$$

$$\therefore E = 1.38 \text{ eV}$$

The work function is 2.29 eV, therefore a photon at 900 nm will not eject any electrons from the metal.

$\therefore$ **B (ANS)**

**Example 6 1999 Question 1, 55%**

The maximum KE is given by KE = hf – W.
Where h is Planck's constant, f is the frequency of the light and W is the work function of the metal.

$\therefore$ **D** **(ANS)**

**Example 7 1999 Question 4, 60%**
The cut-off voltage will remain the same, but the current will increase because the intensity has increased. The increase in intensity means that there will be more photons, causing more electrons to be ejected, this increases the current. Since the same wavelength light (hence same frequency) is being used the energy of the ejected electrons (KE = hf – W) will be the same.
On the graph this means that the cut-off voltage will remain the same but the graph will show a higher current once the voltage is positive.

$\therefore$ **B** **(ANS)**

**Example 8 1996 Question 3, 45%**
Doubling the intensity of the light will not affect the KE of the photoelectrons.
The gradient of the graph is always the same (Planck's constant), and the work function is a property of the metal.
Since the work function and the gradient remain the same the cut-off frequency will remain the same.

$\therefore$ **C** **(ANS)**

**Example 9 1995 Question 3, 60%**
The work function for copper is twice that for potassium. Hence, it could be graphs B or C.
However, the gradients of the graphs must be the same since the gradien = Planck's constant.
**∴ B (ANS)**

**Example 10 1984 Question 48, 51%**
From the definition of the photo-electric effect.
**∴ E (ANS)**

(C is a nice answer, but the electrons would drop back to ground state by emitting a photon, not an electron.)

**Example 11 1978 Question 70, 60%**
From your understanding of the photo-electric effect, it should be clear that electrons cannot have a negative KE.
**∴ C (ANS)**

**Example 12 1978 Question 73, 82%**
The only way to get a current to flow is to eject electrons. This means that the photons need to have sufficient energy for this. The only way to increase the energy of the photon is to increase its frequency.
**∴ (B), D (ANS)**

The answer B, is based on the assumption that the stopping voltage is too large. This is a poor answer because one would have assumed that the stopping voltage had been taken to the lowest value. The question did not say 'one or more answers'.

**Example 13 1974 Question 96, 67%**
If the intensity of the incident light is increased, there will be more photons hitting the emitter every second, so there will be more electrons being emitted. Therefore there will be a greater current. As the frequency of the light has not changed, then the energy of the emitted electrons will be the same. Therefore the cut-off voltage will remain the same.
**∴ B (ANS)**

**Example 14 1974 Question 97, 56%**
If the intensity of the incident light is decreased, there will be less photons hitting the emitter every second, so there will be less electrons being emitted. Therefore there will be a smaller current. If the frequency of the light is increased, then the energy of the emitted electrons will increase. Therefore the cut-off voltage will increase.
**∴ D (ANS)**

**Example 15 1973 Question 92, 52%**

The collector is positive compared to the emitter, so if there isn't a current it is because the electrons are not being emitted from the emitter. To cause a current to flow, the incident like needs to have more energy, ie. A greater frequency (lower wavelength).

∴ **D (ANS)**

**Example 16 1970 Question 91, 63%**

The plates are identical, with the lower one being positive, therefore it will attract any emitted electron. As there is no current, then the photons don't have enough energy to release an electron.

As $E = \frac{hc}{\lambda}$, therefore if there is insufficient energy, this means that $\lambda$ is too long.

∴ **C (ANS)**

**Example 17 1970 Question 93, 70%**

In this instance, the no current is a result of all the electrons not having sufficient energy to reach the collector. Some electrons will be emitted, but none have enough energy.

∴ **D (ANS)**

**Example 18 1970 Question 94, 50%**

If the light intensity is doubled, we now have twice as many photons coming in, but they still have the same energy as before.

Therefore the cut-off voltage will remain the same, but the current will double, as twice as many photons means (approximately) twice as many emitted electrons.

∴ **E (ANS)**

**Short answer solutions**
**Example 19 2010 Question 2, 37%**
Observation 2 was not explained by the wave model.
In the particle model the energy of the incident particles (photons) depends on frequency, given by E = hf. Each photon interacts with one electron.

The energy of the emitted electrons is given by
KE = hf – W, where W is the work function of the metal. As the work function is a constant for each metal, the energy of the emitted electron is a function of the initial photon energy, i.e. its frequency.

Changing the intensity of the light varies the number of photons but not their energy. Therefore, the energy of the emitted electrons does not change, only the number of electrons that are emitted changes.

**Example 20 2009 Question 2, 60%**
The photoelectric effect supports the particle model of light.
The following findings were not able to be satisfactorily explained using a wave model:

- Minimum frequency, i.e. energy, required to emit an electron (threshold frequency)
- Energy of emitted electrons was dependent on the frequency of the incident light
- Below the threshold frequency, increasing the intensity of the incident light did not produce emitted electrons

More intense light was explained by the particle model as more particles with the same energy, whereas the wave model explained more intense light as a wave of greater amplitude.
The PE experiment showed that when light was shone on a metal surface, electrons were ejected.
The wave model predicts that more intense light should produce electrons with greater energy. The particle model predicts more intense light, should produce more electrons with the same energy.

Einstein was able to explain the PE effect using Planck's photon model, which assumes a particle model of light.

**Example 21 2009 Question 5, 47%**
$E_{Kmax}$ is the **maximum** kinetic energy of the photoelectrons emitted from the potassium plate.

*f* is the frequency of the light incident on the potassium plate. This is the light from the light source **after** passing through the filter.

*W* is the work function of the metal, it is the **minimum** energy required to emit a photoelectron.

**Example 22    2009 Question 6, 63%**
From the gradient of the graph will give you Planck's constant in eVs.

The gradient is: $h = \frac{rise}{run}$

$\therefore h = \frac{2 - 0}{(7 - 3) \times 10^{14}}$

$\therefore$ **h =5.0 x 10$^{-15}$ eVs  (ANS)**

The work function is the y-intercept (positive value)

$\therefore$ **1.5 eV        (ANS)**

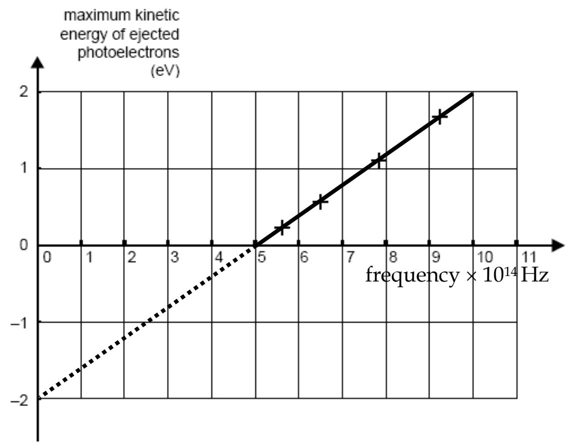
**Note.** You cannot have a minus sign here.

**Example 23    2009 Question 7, 70%**
Doubling the intensity of the light source will increase the number of photons, but will not give the photons any more energy. Therefore the emitted photoelectrons will have the same energy. There will be more photoelectrons emitted.
From the equation

$E_{Kmax} = hf – W$

It is the frequency that sets the energy of the emitted photoelectrons.

**Example 24 2007 Question 1, 56%**
The minimum energy required to remove photoelectrons (work function) is given by extrapolating to the vertical axis.



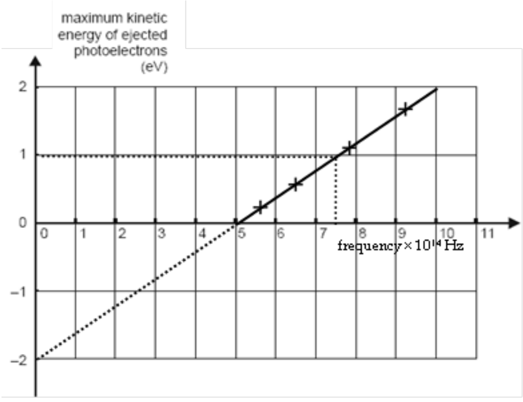

vertical intercept = 2.0 eV
∴ **2.0 eV (ANS)**

**Example 25 2007 Question 2, 56%**

Using $f = \frac{c}{\lambda}$

$= \frac{3 \times 10^8}{400 \times 10^{-9}}$

$= 7.5 \times 10^{14}$ Hz




From the graph,
KE **= 1.0 eV (ANS)**

**Example 26 2007 Question 3, 56%**
The wave model predicts that if you increase the intensity of the light, then this increase in energy will emit photoelectrons. This is not the case.
Einstein's equation for the photoelectric effect KE = hf – W predicts that as you increase the frequency (not the intensity) of the incident photons then the emitted photoelectrons will have more energy. This is a prediction from the particle-like theory of light.

**Example 27 2006 Question 2, 70%**

| Wave model | Particle model |
|---|---|
| Y | Y |
| Y | N |
| Y | N |
| Y | N |

**Example 28 2006 Question 3, 70%**

The minimum energy required is given by the intersection of the graph with the y-axis. ∴ 1.8 eV

This is the energy required to release an electron from the surface of the metal.

The minimum energy required can also be found by $E = hf_{cut-off}$.

∴ $E = 4.14 \times 10^{-15} \times 4.4 \times 10^{14}$

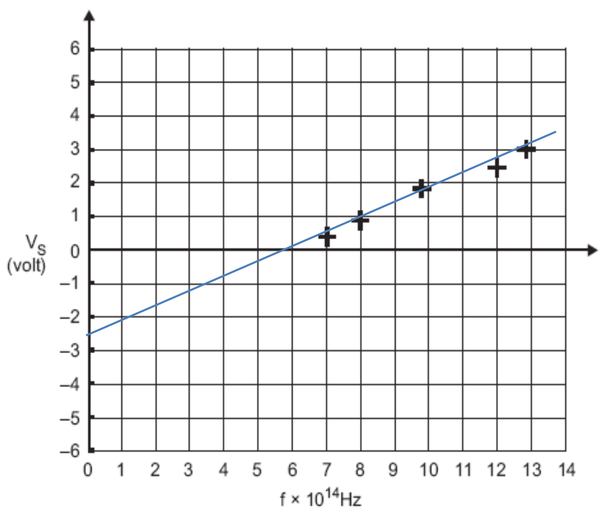
$= 1.82$ eV

∴ **1.82 eV (ANS)**

**Example 29 2005 Question 3, 68%**

The work function is given by the intersection of the graph with the vertical axis. Drawing a line of best fit, gave an intersection of ~2.7 V. This corresponds to sodium. This is a great example of where a clear plastic ruler is really useful in finding lines of best fit. On the actual exam the graph was much larger and a lot easier to use.

∴ **Sodium (ANS)**




**Example 30 2005 Question 4, 68%**

Planck's constant is the gradient of the line. Using the line of best fit, and the widest range of values possible, calculate the rise over the run.

The gradient is $\frac{3.5 - (-2.7)}{14 \times 10^{14} - 0} = \frac{6.2}{14 \times 10^{14}}$

$= 4.4 \times 10^{-15}$ eV s.

∴ **$4.4 \times 10^{-15}$ eV s (ANS)**

The question required you to show working, so just quoting Planck's constant as $4.14 \times 10^{-15}$ eV s did not get any marks. Showing your working means drawing the line of best it AND showing your calculation.

**Example 31 2004 Question 1, 68%**

The energy of a photon is given by E = $\frac{hc}{\lambda}$.

∴ the energy of each photon

$$= \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{550 \times 10^{-9}}$$

**∴ 2.26 eV (ANS)**

**Example 32 2004 Question 2, 68%**

$Ek_{max}$ = hf - W

(hf = E from previous question)

= 2.26 – 2.1 = 0.16 eV

**0.16 eV (ANS)**

**Example 33 2004 Question 3, 50%**

If the KE is 2.80eV

$= 2.80 \times 1.6 \times 10^{-19}$

$= 4.48 \times 10^{-19}$J

∴ $\frac{1}{2}mv^2 = 4.48 \times 10^{-19}$J.

$$\therefore v^2 = \frac{2 \times 4.48 \times 10^{-19}}{9.1 \times 10^{-31}}$$

$= 9.846 \times 10^{11}$

**∴ $v = 9.9 \times 10^{5}$ m $s^{-1}$ (ANS)**

**Example 34 2004 Question 1, 67%**

$KE_{max}$ = hf – W

∴ $KE_{max} = E_{photon} - W$

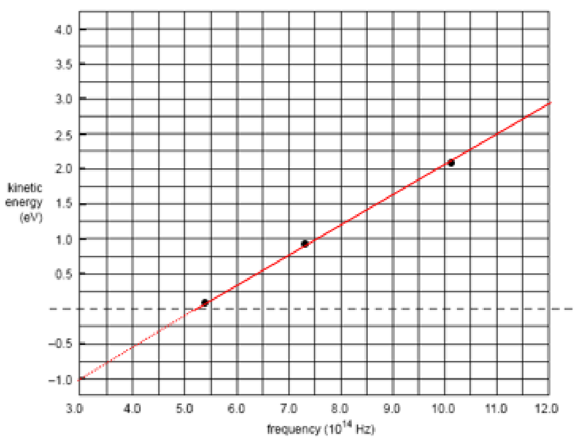
∴ $W = E_{ph} - E_{kmax}$

= 3.0 – 0.9 = 2.1 eV (for blue, or same for UV)

**∴ 2.1 eV (ANS)**

**Example 35 2004 Question 4a, 4b, 65%**

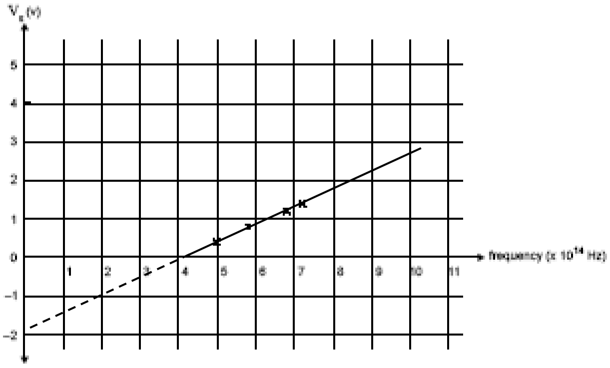
Graph should show three points giving straight line from (3.0,-1.0) to (12, 3.0)



Red is N/A as no electrons emitted.
UV2 is 2.9 eV (+/- 0.2 eV)

**Example 36 2003 Question 5, 47%**

You need to be very careful reading the units on this graph. The vertical axis is in Volts, not the expected "Units of Energy". To convert Volts to 'Energy' you need to multiply by 'e', the charge on an electron.
The work function (or binding energy) is the 'vertical intercept'.
Extrapolating the graph gives a value of 1.9V.




This becomes 1.9eV.
As this is slightly imprecise, the examiners would accept values in the range of
**1.6 → 2.2 eV (ANS)**

**Example 37 2003 Question 6, 44%**

The maximum KE that the photoelectron can have is the initial energy of the light minus the work function.

$\therefore$ hf – W = KE

$\therefore$ $4.1 \times 10^{-15} \times 1.93 \times 10^{16} - 1.9$

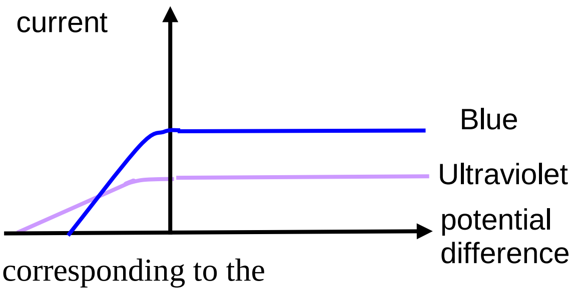
**= 77.2eV (ANS)**

**Example 38 2002 Question 6, 25%**

Using $KE_{max}$ = hf – W.
The cut off potential will correspond to the energy of the electron, if it is expressed in eV. W is given by $hf_0$. (Graph property of straight lines)

$$V_0 = hf - hf_0 = h(f - f_0)$$
$$= 4.14\times10^{-15}(6.25\times10^{14} - 5.50\times10^{14})$$
$$= 0.31V \quad (ANS)$$

**Example 39 2002 Question 7, 46%**




The violet line has: a lower plateau corresponding to the lower intensity producing a smaller current, (less photons, less collisions, less emitted electrons, less current) a larger $V_o$ value due to the higher energy of each photon

**Example 40 2000 Question 1**

$E = \frac{V}{d} \quad \therefore E = \frac{10000}{3 \times 10^{-3}}$

$\therefore \mathbf{E = 3.3 \times 10^{6}\ V\ m^{-1}}$ **(ANS)**

**Example 41    2000 Question 2**

Work done = qV

$= 1.6 \times 10^{-19} \times 10000$

$\mathbf{= 1.6 \times 10^{-15}\ J}$ **(ANS)**

**Example 42    2000 Question 3, 60%**

The only trick to this was using $\frac{c}{\lambda}$ instead of *f*

$E = hf = h\frac{c}{\lambda}$

$\therefore E = 4.14 \times 10^{-15} \times \frac{3.0 \times 10^{8}}{450 \times 10^{-9}}$

$\therefore \mathbf{E = 2.76\ eV}$ **(ANS)**

**Example 43    2000 Question 4, 27%**

This is the minimal energy required to remove an electron from the metal. Any photon that has energy less than this will not remove any electrons.

**Example 44    2000 Question 5, 27%**

$E_{Kmax} = hf - W$

$E_{Kmax} = qV_c$

$E_{Kmax} = 0.47eV$

You can get $V_c$ from the graph, it's the voltage required to stop the current. You then multiply this voltage by the charge on an electron and you get how many eV the $E_{kmax}$ is.

You now can get the work function by itself

$W = hf - E_{kmax}$

*hf* was calculated earlier it is 2.76eV, so

$W = 2.76eV - 0.47eV$

$\therefore \mathbf{W = 2.29\ eV}$ **(ANS)**

**Example 45    1999 Question 2, 60%**

The energy of a photon is given by E = $\frac{hc}{\lambda}$.

∴ the energy of each photon

$= \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{254 \times 10^{-9}}$

**= 4.89 eV** **(ANS)**

**Example 46    1999 Question 3, 45%**

$KE = hf - W$
$\therefore KE = 4.89 - 4.7$
**$= 0.19$ eV** **(ANS)**

**Example 47 1996 Question 1, 37%**
Planck's constant is the gradient of the line. Using the line of best fit, and the widest range of values possible, calculate the rise over the run.

The gradient is $\frac{2.0-0}{7.5\times10^{14}-2.5\times10^{14}}$

$= \frac{2}{5\times10^{14}}$

$= 4.0 \times 10^{-15}$

$\therefore$ **$4.0 \times 10^{-15}$ eV s (ANS)**

**Example 48 1996 Question 2, 50%**
Use If the ejected electron has $4.8 \times 10^{-19}$ J of energy, then it is capable of crossing a potential difference given by $\frac{4.8\times10^{-19}}{1.6\times10^{-19}} = 3.0$

$\therefore$ **3.0 V (ANS)**

**Example 49 1996 Question 4, 19%**
Einstein proposed that light exists as packets of energy called photons. The energy of a photon is given by E = hf, where 'f' is the frequency of the light.
If the energy of the incoming photon was greater than the energy 'binding' the electron to the metal, then a photoelectron could be released from the metal.
Increasing the frequency of the incident light increased the energy of the photoelectrons
Since the energy is given by hf, the intensity of light should not affect the energy of the photoelectrons.
The electron could absorb all the energy of the photon and escape from the metal.
These all supported a particle model for light.
In the wave model for light energy increases with intensity, therefore it would be expected that high intensity light would dislodge electrons regardless of frequency. This was not observed.
Also when low intensity light is turned on, some electrons are emitted immediately, supporting the idea that one electron absorbs one packet of energy.

**Example 50 1996 Question 7, 22%**
Taylor was trying to test for interference with single photons in the apparatus. Since low intensity means very few photons per second, he reduced the intensity until he had only one photon in the apparatus at any-time.
The interference pattern did not change, from very high intensity to very low intensity.

**Example 51 1995 Question 1, 45%**
The work function of the metal (the intercept on vertical axis) is the minimum energy of a light photon that can eject an electron from potassium metal.
From the graph the intercept

**= 1.8 eV (ANS)**

An alternative (not as reliable) method is to use
E = hf at the cut-off frequency.

This gives

$E = 4.14 \times 10^{-15} \times 4.4 \times 10^{14}$

$= 1.8216$

**= 1.8 eV** **(ANS)**

The problem with this method is that the gradient of the line may not be $4.14 \times 10^{-15}$. Use of this value is not really recommended for experimental data. If you found the gradient and used that value for 'h' that would be MUCH better, but would take a lot longer to do.

**Example 52 1995 Question 2, 50%**

Since E = hf, the higher the frequency the greater the incident energy.
Using $KE_{max}$ = hf – W.
Since 'h' and 'W' are both constants, then $KE_{max}$ depends on the frequency. Therefore the greater the frequency the greater the $KE_{max}$ (above the threshold frequency)

**Example 53 1994 Question 1**

Use E = hf.
As both the red and ultra-violet light have the same power, then the **rate** at which energy is being provided varies with frequency. Hence the energy will vary inversely with wavelength.

The ratio of the wavelengths is 3:1, so the red light will have $\frac{1}{3}$ of the energy of the ultra-violet light.
Therefore there will need to be 3 times as many red photons as ultra-violet photons to deliver the same power.

**∴ 3** **(ANS)**

**Example 54 1994 Question 2**

Use $E = hf = h\frac{c}{\lambda}$

$\therefore E = 6.63 \times 10^{-34} \times \frac{3.0 \times 10^{8}}{200 \times 10^{-9}}$

$= 9.945 \times 10^{-19}$

$\therefore$ **$E = 1.0 \times 10^{-18}$ J** **(ANS)**

**Example 55 1994 Question 4**

In the original experiment the energy (hf) of the ultra-violet light was greater than the work function of the metal (Zinc), so photoelectrons were emitted.
The energy of the red light was not sufficient to release an electron from the zinc surface. Increasing the intensity, increase the number of incident photons, but they still have the same energy. Therefore they will still not be able to release a photoelectron.

**Example 56 1994 Question 5**

Use $p = \frac{h}{\lambda}$

$\therefore p = \frac{6.63 \times 10^{-34}}{500 \times 10^{-9}}$

$= 1.326 \times 10^{-27}$

$\therefore$ **$p = 1.3 \times 10^{-27}$ Ns (ANS)**

**Example 57 1991 Question 34**

Use $E = hf = h\frac{c}{\lambda}$

$\therefore E = 6.6 \times 10^{-34} \times \frac{3.0 \times 10^{8}}{6.0 \times 10^{-7}}$

$= 3.3 \times 10^{-19}$

$\therefore$ **$E = 3.3 \times 10^{-19}$ J** **(ANS)**

**Example 58 1991 Question 35**

The laser emits 2.0 mW.
i.e. $2.0 \times 10^{-3}$ $Js^{-1}$
If each photon carries $3.3 \times 10^{-19}$ J, then to get $2.0 \times 10^{-3}$ $Js^{-1}$ requires 'n' photons per second. Where 'n' is found from:
$2.0 \times 10^{-3} = n \times 3.3 \times 10^{-19}$

$\therefore n = \frac{2.0 \times 10^{-3}}{3.3 \times 10^{-19}}$

$\therefore$ **$n = 6.1 \times 10^{15}$ photons/sec (ANS)**

**Example 59 1991 Question 36**

If one electron is emitted for every $10^{6}$ photons, then the number of electrons emitted every second is $6.1 \times 10^{9}$ electrons.

The current is measured in amp, which is coulomb per second, therefore the current is

$6.1 \times 10^{9} \times 1.6 \times 10^{-19}$

**$= 9.8 \times 10^{-10}$ A (ANS)**

**Example 60 1978 Question 71, 70%**

This is the x-intercept for the Lithium graph.

**$\therefore$ $6 \times 10^{14}$ Hz (ANS)**

**Example 61 1978 Question 72, 38%**

To have enough energy to remove an electron means that the energy needs to be greater than the work function.

The work function is the y-intercept.

**$\therefore$ $6 \times 10^{-19}$ J (ANS)**

Note that this answer MUST be positive.

**Example 62 1974 Question 98, 36%**

It takes 2eV to stop the most energetic electron. (From the graph)

**$\therefore$ 2eV (ANS)**

**Example 63 1973 Question 93, 38%**

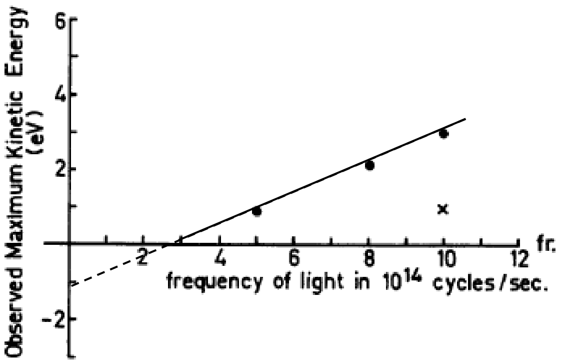
The longest wavelength will occur at the lowest frequency. This will be the cut-off frequency which is the 'x intercept'. (See graph below)

Use $c = f\lambda$

$\therefore 3.0 \times 10^{8} = 3 \times 10^{14} \times \lambda$

**$\therefore \lambda = 1.0 \times 10^{-6}$ m (ANS)**

**Example 64 1973 Question 94, 14%**
To emit an electron, the incident light has to have energy greater than the binding energy (Work function).
This is the intercept on the y axis.




From the extrapolation of the graph.

$\therefore$ **1.2 eV (ANS)**

**Example 65 1973 Question 95, 17%**
Planck's constant is the gradient of the graph. You must use values that are on your line of best fit.
My line goes through the points (10 x $10^{14}$ Hz, 3 eV) and (3 x $10^{14}$, 0)

The gradient is: $h = \frac{\text{rise}}{\text{run}}$

$\therefore h = \frac{3.0 - 0}{(10 - 3) \times 10^{14}}$

$\therefore$ **h =4.3 x $10^{-15}$ eVs (ANS)**

**Example 66 1973 Question 96, 16%**
There are few ways of doing this. The gradient of this graph will be Planck's constant, so the line will be parallel to the original. From this we can find the 'y intercept'. The other method is to realise that the gradient is the same for both graphs, so the y intercept will be as far below the value for caesium as is the result for 10 x $10^{14}$ Hz.
From the graph, the 'x' is 2 eV below the line of best fit.
Therefore the y intercept will now be -3.2 eV.
Therefore the work function for copper

**= 3.2 eV (ANS)**

**Example 67 1970 Question 92, 23%**
The stopping potential is 2.0 eV, from the graph. When the current is zero, no electrons are emitted from the metal.
If the incident light had 5 eV, and the maximum KE of the emitted electron was 2.0 eV, then the electron needed 3 eV to leave the metal.

$\therefore$ **3.0 eV (ANS)**