Checkpoints Chapter 18
Particle properties of Light
Multiple choice questions

Question 1

The momentum of a photon is given by

$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{520 \times 10^{-9}}$

$= 1.28 \times 10^{-27}$ Ns

∴ **B (ANS)**

Question 2

Power is the rate of using energy. So the photons leaving the searchlight are taking 5.0 kJ of energy every second.
If we find the energy of each photon, then we can use this, to find the number of photons leaving the light each second.
The energy of a photon is given by

$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{520 \times 10^{-9}}$

$= 3.825 \times 10^{-19}$ J.

$\therefore 5.0 \times 10^{3} = n \times 3.825 \times 10^{-19}$ J.

$\therefore n = 5.0 \times 10^{3} \div 3.825 \times 10^{-19}$

$\therefore n = 1.3 \times 10^{22}$ photons per second.

You need to use the fact that momentum is conserved in all collisions.

$\therefore F \Delta t = m \Delta v$

For a perfectly reflecting surface, the photons will bounce of the surface with the same momentum that they hit the surface.
Therefore the change in momentum is

$p_f - p_i = 2p$

So in each second the change in momentum = 2 × 'the number of photons' × 'the momentum of each photon'

$= 2 \times 1.3 \times 10^{22} \times 1.28 \times 10^{-27}$

$= 3.3 \times 10^{-5}$ N

∴ **B (ANS)**

Question 3

If the mirror is replaced by a perfectly absorbing surface, then the change in momentum will = p. This is because when the photons are absorbed, they transfer their momentum to the surface. Each photon loses its momentum.
So the change = $0 - p_i$.
This has a magnitude of p_i.
In this case, the change of momentum has been halved.

∴ **B (ANS)**

Question 4

To measure the maximum energy of the emitted electrons, you need to see what value of negative voltage it has enough energy to work against. This will be the largest voltage that you can still detect a current at.

∴ **D (ANS)**

Question 5

Einstein suggested that light was not a continuous wave, but instead travels in discrete packets or QUANTA. All light of a certain frequency comes in packets that have the same amount of energy. These quanta of light energy are called photons.

Einstein's explanation of the photoelectric effect was that each photon of light gave up its energy completely when it collided with an electron in the metal. The energized electron used up some of this energy in overcoming the binding force of the atoms in the metal and escaped with the remaining energy.
The energy that the electron uses up to escape from the metal is called the binding energy or the work function (W) of the metal. This quantity varies from metal to metal.

The photoelectric effect cannot be explained by the wave model for light. In particular, the fact that the energy of ejected electrons does not depend on the intensity of light contradicts wave properties.

Einstein explains why the emission of electrons can occur at very low intensities, because the incident light photons have enough energy to eject an electron. He also explains why below a certain frequency, electrons will not be ejected, because the incident photons don't have sufficient energy to eject an electron.

∴ **D (ANS)**

Question 6

The interference pattern when applied to particles or photons, shows a dark region because of an absence of particles or photons.

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

Question 7

The intensity of a light source is directly proportional to the number of photons.

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

Question 8 (2010 Q5, 2m, 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.

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

Question 9 (2010 Q6, 3m, 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.

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

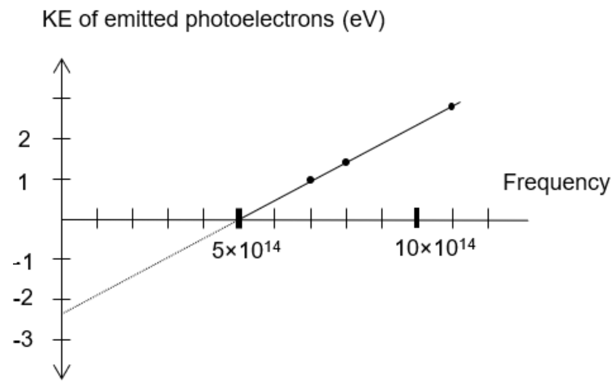
Question 10

The photon gives up all its energy to release the electron, and only one photon is required.

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

Extended questions

Question 11a



Question 11b

Planks constant is the gradient of the line. Using the data supplied (as the line gores through these points)

$$\frac{2.8-1}{(11-7)\times10^{14}}$$

4.5×10^{-15} eVs(ANS)

This answer is different to the one in the book.

Question 11c

The work function is given by the intersection of the y-axis. Reading from the graph the value for the work function is 2.3 eV

~2.3 eV (ANS)

The work function can also be calculated by finding the 'y-intercept' of the graph.

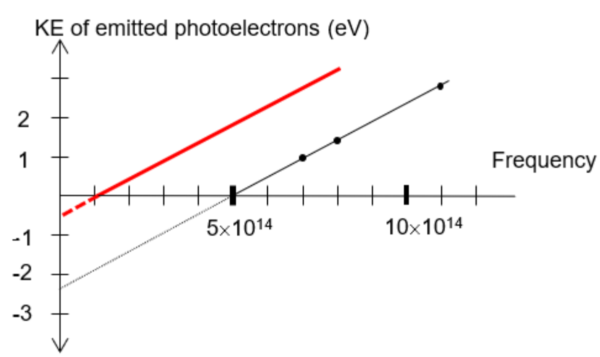
This is given by the gradient x 5.0 x 10^{14}

$\therefore$ 4.5 x 10^{-15} x 5.0 x 10^{14}

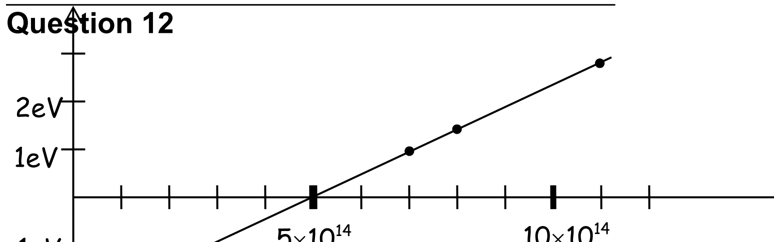
= 2.25

~ 2.3 eV (ANS)

Question 11d

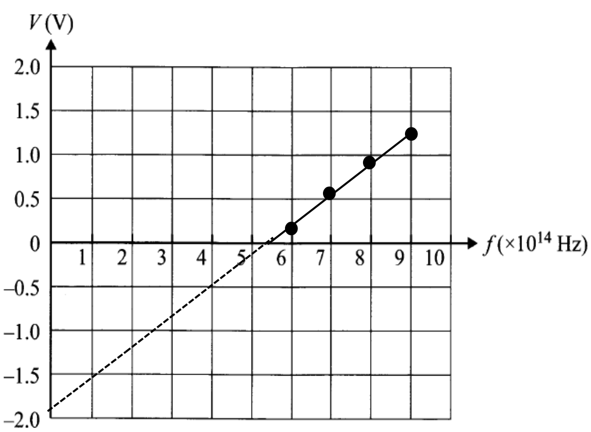


Question 12



This phenomenon caused problems for the proponents of the wave theory of light because the wave theory of light links the energy of the light to the intensity of the light. This phenomenon does not depend on the intensity of the light, only the frequency of the light. This is from E = hf. The photoelectric effect is used as evidence for the particle-like nature of light.

Question 13a (2016 Q19a, 2m, 90%)



Question 13b (2016 Q19b, 3m, 57%)

Plank's constant is the gradient of the line. You MUST use two points from your graph.

Use $h = \frac{1.20 - 0.16}{(9.0 - 6.0) \times 10^{14}}$

$\therefore h = \frac{1.04}{3.0 \times 10^{14}}$

∴ h = 3.5 × 10^{-15} eVs (ANS)

Horizontal intercept

∴ 5.5 × 10^{14} Hz (ANS)

Vertical intercept (modulus)

∴ 1.9 eV (ANS)

Question 13c (2016 Q19c 2m, 22%)

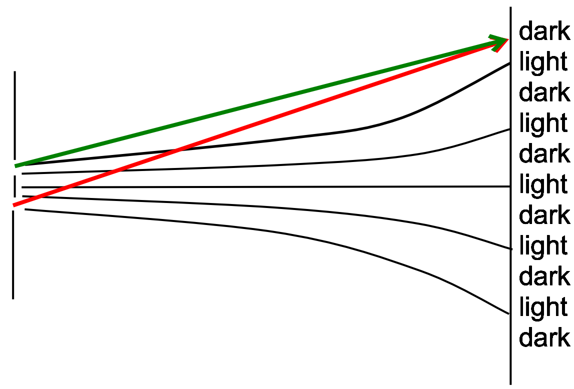
The work done to stop the photoelectron is given by qV, where q is the charge and V is the voltage.
In this case the charge is 'e'.
Therefore the work done to stop the photoelectron is 1 × V when measured in eV, which is the voltage required to stop the most energetic photoelectron and hence reduce the current to zero.

The work done to stop the photoelectron equals the KE of the photoelectron.

Question 13d (2016 Q19d, 3m, 57%)

The graph will be identical to the original.
They support the particle model for light.
The particle model infers that an increase in the intensity of the light, would create more photons, but still with the same energy. This increase in the number of photons may lead to more collisions and more photoelectrons being released, but the photoelectrons would still have the same energy.

Question 14



The path difference between the two sources must be $\frac{5}{2}\lambda$. This is due to the fact that the central maximum has a path difference of 0 λ, and the first dark band has a path difference of $\frac{1}{2}\lambda$, so the path difference to the third dark band must be $\frac{5}{2}\lambda$

Question 15

The change in momentum will be twice the original momentum. This is because the final momentum = initial momentum, but with a change of direction. ∴The change in momentum = $2p_i$.

Initial momentum = $\frac{h}{\lambda}$

$= \frac{6.63 \times 10^{-34}}{1.0 \times 10^{-8}} = 6.63 \times 10^{-26}$

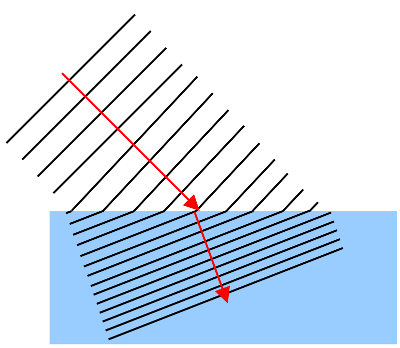
∴ change in momentum = $2 \times p_i$

1.3×10^{-25} N s (ANS)

Question 16

The wave theory predicts that when the light source is very low, it will take some time before enough energy has been transferred to an electron to enable it to leave the metal. The photon theory proposed by Einstein explains why the emission of electrons can occur at very low intensities, because the incident light photons have enough energy to eject an electron. So when the surface is hit by low intensity light it is possible for the photons to collide with the electrons and give up their energy. This allows the electrons to escape the metal surface.
This shows that the electrons are being released due to the collision of individual photons.

Question 17
Light travels at different speeds in different materials. In a vacuum, it travels at 3 x 10^8 m s^{-1}. In other transparent materials, such as glass and water, the speed is reduced. This reduction in speed causes the wavefront in the material to lag behind the wavefront outside the material. This causes the direction of the wavefront to change.



Question 18

The energy of light with a wavelength of 5 × 10^{-7} m is given by

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

$$= \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{5 \times 10^{-7}}$$

= 2.48 V.

The energy of the photons is greater than the work function, so it would be possible for these photons to cause the metal to emit electrons with a KE of
2.48 – 1.8 = 0.68 eV.
Yes (ANS)

Question 19 (2010 Q1, 3m, 70%)

Young's double slit experiment with light demonstrated interference, which was a wave effect. Young's experiment showed that the light from both slits interfered with each other and produced a pattern of light and dark lines. The interference was both constructive and destructive from the superposition of waves.
The particle model predicted that two bands would appear on the screen behind the slits as sharp shadows, which are not observed.

Question 20a (2012 Q1a, 1m, 70%)

The maximum wavelength will be at the threshold frequency. The speed of light is 3.0 x 10^8.
∴ c = fλ
∴ 3.0 x 10^8 = 7.40 x 10^{14} x λ
∴ λ = 4.05 x 10^{-7}
∴ λ = 405 nm (ANS)

Examiners comment
A common mistake was not converting the unit from metre to nanometre.

Question 20b (2012 Q1b, 3m, 33%)

The particle model predicts that increasing the intensity, will increase the number of incident photons, but the photons will still have the same energy. Therefore the photons will not have sufficient energy to release an electron from the metal surface. Therefore the will not be any current.
The wave model predicts that increasing the intensity will increase the energy to a level to eject photoelectrons.

Examiners comment
There were two aspects to this question: to explain how the observation supported the particle model of light and to explain how it did not support the wave model of light.

This question was very poorly done, with many students simply copying, from their A4 sheet of notes, generic statements that did not address the question.

Question 20c (2012 Q1c, 2m, 80%)

$KE_{max} = hf – W$

$\therefore$ KE = 4.14 x 10^{-15} x 7.50 x 10^{14} – 2.28

$\therefore$ KE = 0.825 eV (ANS)

Question 20d (2012 Q1d, 1m, 40%)

If the photoelectrons have a KE of 0.825 eV, then it will take 0.825 V to stop them.

$\therefore$ 0.825 V (ANS)

Question 21 (2015 Q20a, 2m, 60%)

Photoelectric effect.
This experiment showed that increasing the intensity of the incident light, increased the number of photons, but not their energy. This produced more photoelectrons, but with the same energy. The wave model predicted that there would be the same number of photoelectrons ejected, but with more energy.
There is a threshold frequency below which no electrons are emitted regardless of the intensity of the light.
That electrons were ejected immediately no matter how low the intensity of the light, is also evidence for a particle model of light.

Question 22a (2013 Q21a, 1m, 40%)

Using the stopping voltage, 1.85,
Maximum KE = Vq
= 1.85 x 1.6 x 10^{-19}
= 2.96 x 10^{-19} J (ANS)

Question 22b (2013 Q21b, 2m, 35%)

It is best to work in eV.
Use $KE_{max} = hf – W$

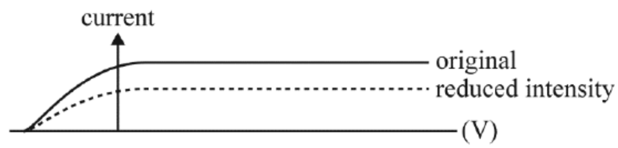
$KE_{max} = hf – W$

$\therefore$ 1.85 = 4.14 x 10^{-15} x 1.00 x 10^{15} – W

$\therefore$ W = 4.14 – 1.85

$\therefore$ W = 2.29 eV (ANS)

Question 22c (2013 Q21c, 2m, 60%)



With the intensity of the light reduced, there will be less photoelectrons released from the metal, so the current will be reduced (y – intercept).
As the same light is used, the max KE of the ejected photoelectrons will remain the same, therefore the cut-off voltage will remain the same (x – intercept).

Question 22d (2013 Q21d, 2m, 25%)

The new frequency of the incident photons is now less than the threshold frequency.
Therefore the photons do not have enough energy to release (free) any electrons.
The energy of the incident photons is less than the work function.

Question 23a (2014 Q20a, 2m, 75%)

Use $W = hf_0$

$\therefore$ W = 6.63 × 10^{-34} × 1.8 × 10^{15}

$\therefore$ W = 11.934 × 10^{-19}

$\therefore$ W = 1.2 × 10^{-18} J (ANS)

Question 23b (2014 Q20b, 3m, 27%)

The particle model infers that an increase in the intensity of the light, would create more photons, but still with the original energy. This increase in the number of photons may lead to more collisions and more photoelectrons being released, but the photoelectrons would still have the same energy (as initially).

Question 24a (2015 Q18a, 1m, 88%)

From the graph, the threshold frequency is the lowest frequency that emits a photoelectron.
This is the horizontal intercept.

$\therefore$ 5 × 10^{14} Hz (ANS)

Question 24b (2015 Q18b, 2m, 60%)

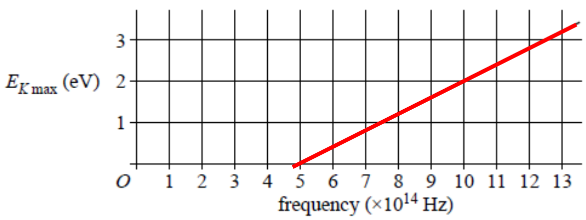
Planck's constant is the gradient of the line. Use two points from the graph. The best two are (2, 10 ×10^{14}) and (0, 5 × 10^{14})

$$\therefore h = \frac{2-0}{10\times10^{14} - 5\times10^{14}}$$

∴ h = 4.0 × 10^{-15} eV s (ANS)

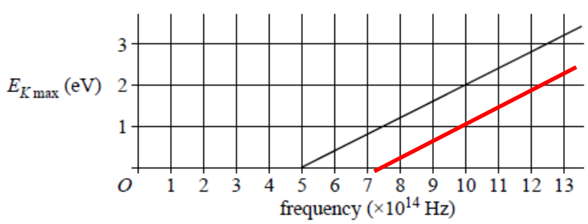
Question 24c (2015 Q18c, 1m, 55%)

Increasing the intensity of the light will not affect the threshold frequency. The gradient must remain the same. Therefore the graph is identical to the original.



Question 24d (2015 Q18d, m, 55%)

Increasing the work function means that the vertical intercept is 50% larger. This means that the horizontal intercept needs to be 50% larger, therefore 7.5 × 10^{14} Hz. The gradient of the line must remain the same.



Question 25 (2013 Q22d, 3m, 60%)

The statement is **incorrect**.

(I prefer you to start your answer with this statement, because then the marker knows where you are trying to go with your explanation.)

Two more marks, two more reasons.

Young's experiment demonstrates interference. Interference is a wave phenomenon.

Particles would produce just two bands on screen

Question 26a (2017 Q17a, 2m, 35%)

Use V = hf –hf_0

Where hf_0 is the work function for sodium.

= 4.14 × 10^{-15} × 5.50 × 10^{14}

= 2.277 eV

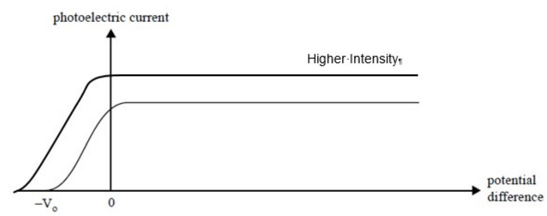
∴ V = 4.14 × 6.25 × 10^{-15} – 2.277

∴ V = 2.5875 – 2.277

∴ V =0.3105

∴ V = 0.31 V (ANS)

Question 26b (2017 Q17b, 2m, 60%)



Question 26c (2017 Q17c, 5m, 42%)

There is a negligible time delay in the emission of photoelectrons. The particle model predicts that if the photons have sufficient energy, then they will transfer this to an electron and a photoelectron will be released immediately, and if they don't have enough energy then a photoelectron will never be emitted. The wave model predicts that if the wave doesn't have sufficient energy to release a photoelectron then the energy will build over time, and eventually a photoelectron will be emitted. This doesn't occur.

The threshold frequency. There is a frequency below which photoelectrons cannot be emitted. The particle model states that the energy of the photon is given by E = hf, so the higher the frequency the more energy the photon has. The particle model states that the energy does not depend on the intensity. The wave model assumes that increased intensity means a wave with a larger amplitude, and that this should produce more photoelectrons. This is not the case

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