Checkpoints Chapter 15
Wave – Particle properties of Light

Question 622

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

$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{520\times10^{-9}}$

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

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

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

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

1.3×10^{22} photons/sec (ANS)

Question 623

The momentum of a photon is given by

$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{520\times10^{-9}}$

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

1.28×10^{-27} Ns (ANS)

Question 624

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.
This means that 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

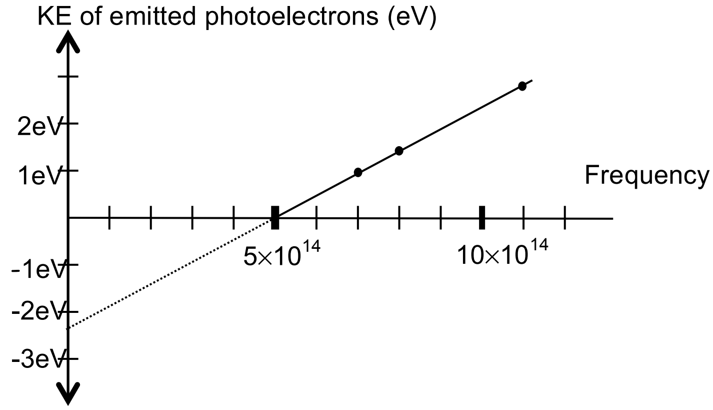
3.3×10^{-5} N (ANS)

Question 625

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 626



Question 627

Planks constant is the gradient of the line.
Using the data supplied

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

4.5×10^{-15} eVs (ANS)

Question 628

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)

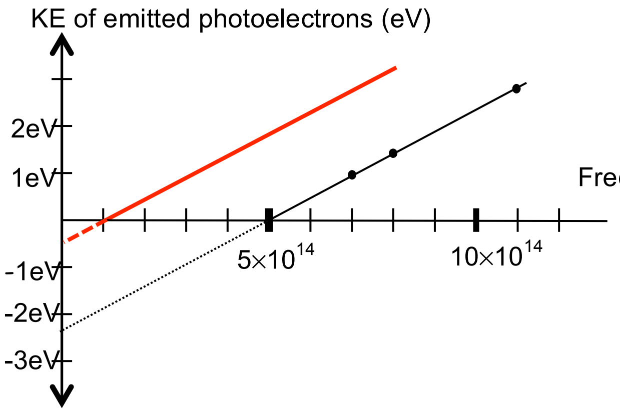
The work function can also be calculated by finding the 'y-intercept' of the graph.
This is given by the gradient x 5.0 x 10^{14}

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

$= 2.25$

~ - 2.3 eV (ANS)

Question 629



Question 630

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 631

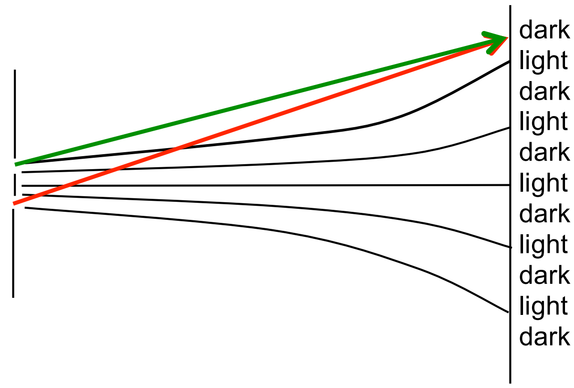
This phenomenon caused problems for the proponents of the wave theory of light because the wave theory of light links the energy of the light to the intensity of the light. This phenomenon does not depend on the intensity of the light, only the frequency of the light. This is from E = hf. The photoelectric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

Question 632

The central maximum will always be point of constructive interference, since the path length from both slits is the same. Since, both the point sources (slits) are being hit by the same light the waves from these two point sources will be in phase. Therefore M will be a bright point.

Bright **(ANS)**

Question 633



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 0λ, 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 634

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

$$= \frac{6.63\times10^{-34}}{1.0\times10^{-16}} = 6.63 \times 10^{-18}$$

∴ change in momentum = $2 \times p_i$

1.3×10^{-17} Ns **(ANS)**

Question 635

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

∴ the energy of each photon

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{5.0\times10^{-7}}$$

$= 3.978 \times 10^{-19}$J

∴ To make a beam of 1.0 kW, you need 1000 Joules every second.

∴ 1000 = 'n' $\times 3.978 \times 10^{-19}$J

∴ n = 1000 ÷ 3.978×10^{-19}J

2.5×10^{21} photons/sec **(ANS)**

Question 636

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.

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

Question 637

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 638

The energy of a photon is given by

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

$\therefore$ the energy of each photon

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{5.0\times10^{-7}}$$

$= 3.978 \times 10^{-19}$J

$\therefore$ To make a beam of 1.0 mW, you need 1.0×10^{-3} Joules every second.

$\therefore$ 1.0×10^{-3} = 'n' $\times$ 3.978×10^{-19}J

$\therefore$ n = $1.0 \times 10^{-3} \div 3.978 \times 10^{-19}$J

$\therefore$ **2.5×10^{15} photons/sec** **(ANS)**

Question 639

Use $p = \frac{h}{\lambda}$, for a mirror the change in momentum for N photons will be 2N

$$2N \times \frac{h}{\lambda} = 2 \text{ x } 10^{20} \text{ x } \frac{6.63\times10^{-34}}{5.0\times10^{-7}}$$

$\therefore$ **$2.7 \text{ x } 10^{-7}$ Ns** **(ANS)**

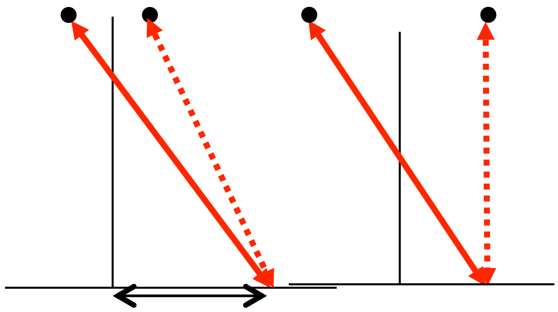
Question 640

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

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

Question 641

The wider the separation of the sources, the narrower the pattern. If the full arrow is λ longer than the dotted arrow, then the distance to the first bright region from the central bright region is shown below.



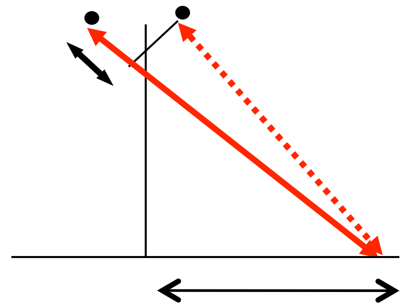
If the sources are moved further apart, but the full arrow remains λ longer than the dotted arrow, then the distance to the first bright region from the central bright region has decreased.

∴ A (ANS)

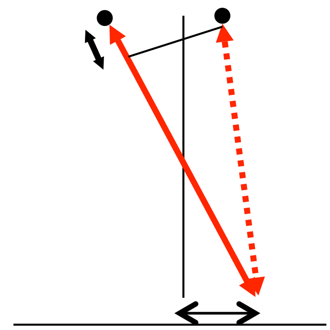
Question 642

As light travels from one medium to another, the wavelength of the light changes according to Snell's Law.
When light travels from low refractive index to higher refractive index, the light slows down.
The frequency of the light must stay the same so if v = f λ, then as v slows down, λ must also decrease.
A decrease in λ will mean that the interference pattern contracts.
If the full arrow is λ longer than the dotted arrow, then the distance to the first bright region from the central bright region is shown below.

Imagine the triangle created as an isosceles triangle. The distance shown by the arrow is λ



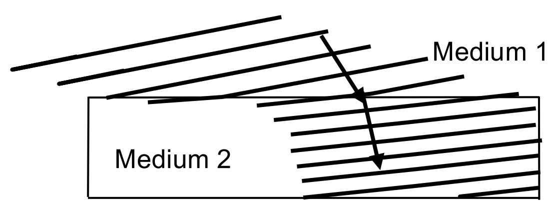
As λ decreases the pattern becomes narrower.



A and E (ANS)

Question 643
The intensity of a light source is directly proportional to the number of photons.
A (ANS)

Question 644
Wave theory predicts that as the wave travels from one medium to another its speed will decrease when it bends towards the normal. This is easily observed with water waves.



The wavelength decreases in the higher refractive index, and since v = f λ, then λ must also decrease. The frequency (number of wave-fronts passing any point) must stay the same.

Question 645

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 646 (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 647 (2010 Q2, 3m, 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.

This question was poorly done on the exam, with a lot of students not answering the question and relying on the notes for general information.

Question 648 (2010 Q3, 2m 80%)

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

∴ the energy of the photon

$$= \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{580 \times 10^{-9}}$$

= 2.14 eV

∴ 2.14 eV (ANS)

Question 649 (2010 Q4, 2m 50%)

The point 'C' is the bright central maximum is in the middle of the diagram.
This means that the path difference to 'X' is 2λ and the path difference to 'Y' is $\frac{5}{2}\lambda$.

∴ $S_2X - S_1X = 1160$ nm

$= 2\lambda$

∴ $\lambda = 580$ nm

∴ $S_2Y - S_1Y = \frac{5}{2}\lambda$

∴ $S_2Y - S_1Y = 1450$ nm (ANS)

Question 650 (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.

D (ANS).

Question 651 (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.

A (ANS)

Question 652 (2011 Q1, 2m, 65%)

P is second dark band from the central band C,

∴ path diff = 1.5 x wavelengths
= 1.5 x 560
= 840 nm (ANS)

Remember that the question stated "Show your working."

Question 653 (2011 Q2, 1m, 80%)

As the separation between the slits and the screens increases so will the size of the pattern shown on the screen.
Therefore the spacing of the bright and dark bands will increase.

Question 654 (2011 Q3, 2m, 70%)

Decreasing the separation of the slits (i.e. d is decreased) increases the separation of the bands in the pattern. This is to accommodate the path difference to P (for instance) to remain the same.

Question 655 (2011 Q4, 3m, 70%)

Young's experiment demonstrated an interference pattern of bright and dark bands formed from constructive and destructive interference.
He understood this to be a property of waves, therefore he concluded that light exhibited wave-like properties.

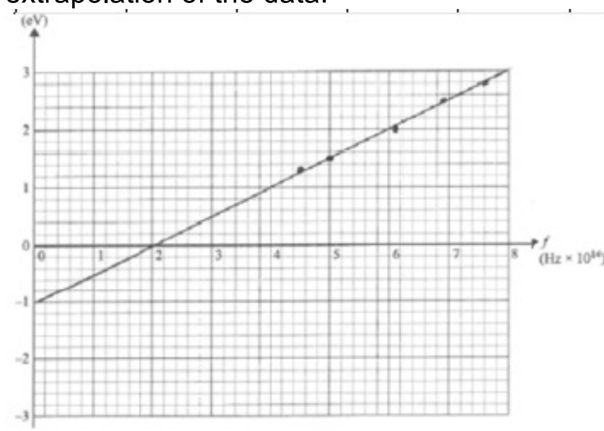
Question 656 (2011 Q5, 2m, 20%)

Electrons are being ejected from the metal plate by the light source. These electrons are collected at the 'collector electrode'. Therefore there is a current.

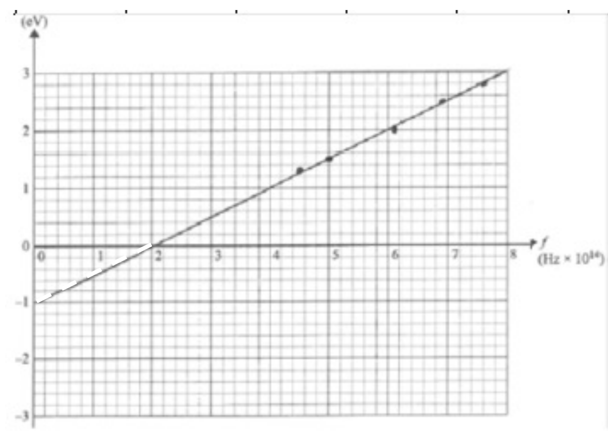
As the stopping potential is increased the current will decrease. When the stopping potential is great enough, even the most energetic photoelectron emitted will not have enough energy to make it to the collector electrode. Hence the current will drop to zero.

Question 657 (2011 Q6, 3m 77%)

This is the graph that was included in the chief assessors report. I think that it is incorrect. The line below the horizontal axis cannot be a complete line, it needs to be a dashed line to demonstrate that it doesn't exist, it is the extrapolation of the data.



The line below the axis must be dashed.



Question 658 (2011 Q7, 2m, 60%)

To find Planck's constant, you need to find the gradient of the line.
Use two points that are
1) easy to read,
2) as far apart as is possible,
3) on your line of best fit.

Therefore 7.6 x 10^{14}, 2.8 V is one point,
2.0 x 10^{14}, 0 V is the other.

The gradient = $\dfrac{2.8-0}{(7.6-2.0)\times 10^{14}}$

= 5.0 x 10^{-15}eVs (ANS)

Examiners comment
It is not appropriate to use data points unless they are on the line of best fit. Students who gave the accepted value from the data sheet scored zero.

Question 659 (2011 Q8, 2m, 45%)

The longest wavelength is the same as the shortest frequency,

∴ f = 2.0 x 10^{14}

Using c = fλ

gives 3.0 x 10^{8} = 2.0 x 10^{14} x λ

∴ λ = 1.5 X 10^{-6}

∴ λ = 1500 nm (ANS)

Question 660 (2011 Q9, 3m 53%)

Examiners comments

The question related to Einstein's conclusions about the nature of light, not the details of the experiment.

Einstein drew the following conclusions from the observations of photoelectric experiments:

1. Light behaves like particles called photons whose energy is proportional to their frequency,

E = hf.

2. The intensity of light is proportional to the number of photons.

Question 661 (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 662 (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 663 (2012 Q1c, 2m, 80%)

KE_{max} = hf – W

∴ KE = 4.14 x 10^{-15} x 7.50 x 10^{14} – 2.28

∴ KE = 0.825 eV (ANS)

Question 664 (2012 Q1d, 1m, 40%)

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

∴ 0.825 V (ANS)

Question 665 (2012 Q2a, 2m, 40%)

The energy of each photon is given by hf or $\frac{hc}{\lambda}$.

$$\therefore E = \frac{6.63\times10^{-34}\times3\times10^{8}}{612\times10^{-9}}$$

= 3.25 x 10^{-19}

If the energy output of the laser is 5.0 x 10^{-3} J/s, then it must emit

$$\frac{5.0\times10^{-3}}{3.25\times10^{-19}}$$

= **1.54 x 10^{16} photons per second. (ANS)**

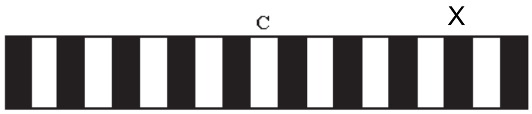
Question 666 (2012 Q2b, 2m, 60%)

The laser provides a coherent light source. Therefore the path difference for the two beams reaching the central point is zero. They will interfere constructively, so there will be a local maximum, which is seen as a bright band.

Question 667 (2012 Q2c, 3m, 60%)

The path difference is $\frac{2.142\times10^{-6}}{612\times10^{-9}}$ = 3.5 λ.

Therefore the point X will be on the 4th dark band to the right of C. Each dark band indicates destructive interference, where the path difference is a multiple of ½λ.



Question 668 (2012 Q2d, 2m, 40%)

With the new wavelength, 2λ must be the same as 1½λ in the original wavelength.

∴ $2\lambda_{new} = 1.5 \times 612$

∴ λ_{new} = 459 nm (ANS)

Question 669 (2013 Q19a, 1m, 90%)

Use E = hf

∴ $E = 6.63 \times 10^{-34} \times 6.7 \times 10^{14}$

∴ $E = 4.44 \times 10^{-19}$ J (ANS)

Question 670 (2013 Q19b, 1m, 80%)

Use c = fλ

∴ $3.0 \times 10^{8} = 6.7 \times 10^{14} \times \lambda$

∴ $\lambda = 4.5 \times 10^{-7}$ m (ANS)

Question 671 (2013 Q21a, 1m, 40%)

Using the stopping voltage, 1.85,

Maximum KE = Vq

$= 1.85 \times 1.6 \times 10^{-19}$

$= 2.96 \times 10^{-19}$ J (ANS)

Question 672 (2013 Q21b, 2m, 35%)

It is best to work in eV.

Use $KE_{max} = hf - W$

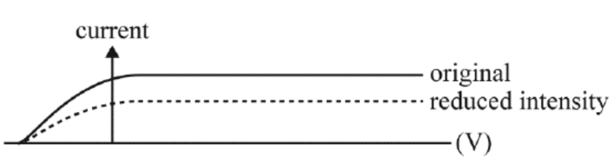
$KE_{max} = hf - W$

∴ $1.85 = 4.14 \times 10^{-15} \times 1.00 \times 10^{15} - W$

∴ $W = 4.14 - 1.85$

∴ W = 2.29 eV (ANS)

Question 673 (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 674 (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 675 (2013 Q22a, 2m, 50%)

Bright or a local maximum.
The path difference from the double slits to the **centre** of the pattern is zero, therefore constructive interference will occur.
You needed to be specific about the pattern in the centre.

Question 676 (2013 Q22b, 1m, 60%)

Lower frequency means a longer wavelength, therefore it is further to each maximum and minimum, i.e. the pattern is more spread out.

∴ D ANS)

Question 677 (2013 Q22c, 3m, 33%)

Determine the wavelength of the light, (in metres).
Use:
The second bright band has a path difference of 2λ

∴ $2\lambda = 1.4 \times 10^{3}$ nm

$= 1.4 \times 10^{-6}$ m

So λ was 7×10^{-7} m.
The PD to the first dark band is λ/2,

∴ 3.5×10^{-7} m (ANS)

Question 678 (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 679 (2014 Q19a, 1m, 60%)

The path difference to the second bright band is 2λ.

∴ 2 × 420 = **840 nm** **(ANS)**

Question 680 (2014 Q19b, 2m, 45%)

If the point P is now on the second dark band, this means that the path difference is now 1.5λ.

∴ $840 = 1.5\lambda_{new}$

∴ $\lambda_{new} = \frac{840}{1.5}$

∴ $\boldsymbol{\lambda_{new} = 560}$ **nm** **(ANS)**

Question 681 (2014 Q20a, 2m, 75%)

Use $W = hf_0$

∴ $W = 6.63 \times 10^{-34} \times 1.8 \times 10^{15}$

∴ $W = 11.934 \times 10^{-19}$

∴ $\mathbf{W = 1.2 \times 10^{-18}}$ **J** **(ANS)**

Question 682 (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 683 (2014 Q21a, 2m, 70%)

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

∴ $\lambda = \frac{hc}{E}$

∴ $\lambda = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{4.1}$

∴ $\boldsymbol{\lambda = 3.0 \times 10^{-7}}$ **m** **(ANS)**

Question 684 (2014 Q21b, 1m, 60%)

smaller than

Question 685 (2014 Q21c, 2m, 35%)

This is a diffraction pattern. The diffraction (bending) of the photon path varies as $\frac{\lambda}{d}$,

So the pattern spreads more as λ increases and the pattern spreads less as 'd' (the size of the aperture) increases.
