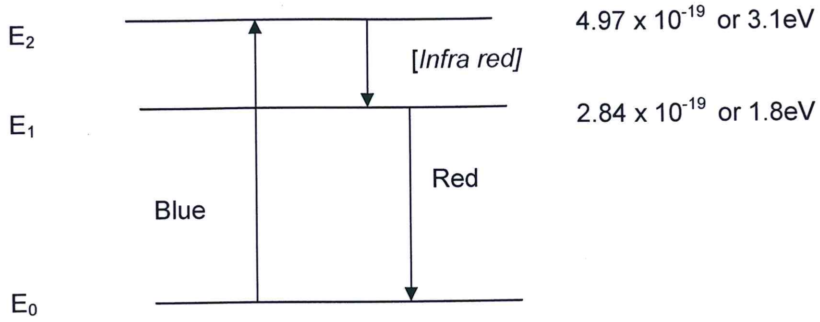
Exam Solutions
Chapter 8.1 - Spectra

Answer 1 2010:1:4

(5 marks)

In April 2009 *New Scientist* magazine reported the discovery of several species of fish that emit red light as a means of communication. This was surprising because these fish swim at depths where wavelengths corresponding to red light do not penetrate but blue light does. The fish might produce red light using a fluorescent protein that absorbs blue light and then emits red.

(a) Draw an energy level diagram showing possible electron transitions taking place in the atoms of the fluorescent protein that could give rise to the observed phenomena. (2 marks)



Description	Marks
Lines drawn and spacing appropriate. (must show red more than half of blue gap	1
Arrows appropriate, emission/absorption.	1
	Total 2

(b) Calculate the energy in joules of a photon of blue light and a photon of red light. Blue light has wavelength of 400 nm and red light 700 nm. Use the energy values to label the transitions in the diagram you drew in part (a). (3 marks)

Description	Marks
Use $E = hc/\lambda$ then wavelengths are red = 7×10^{7} m and blue = 4×10^{-7} m E (red) = 2.84×10^{-19} J or 1.8 eV Note must have answer in Joules for full marks E (blue) = 4.97×10^{-19} J or 3.1 eV	 1 1
Labels on diagram.	1
	Total 3

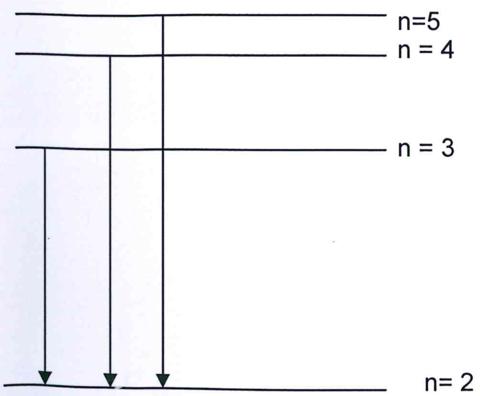
Answer 2 2010:2:14

(11 marks)

There are three lines in the emission spectrum of hydrogen that occur in the visible part of the electromagnetic spectrum. These involve transitions to the n = 2 energy level.

The three lines have the wavelengths; 6.60×10^{-7} m, 4.90×10^{-7} m and 4.40×10^{-7} m.

(a) Draw an energy level diagram to illustrate the transitions from the n = 3, 4, 5 levels to the n = 2 level. Label the levels n = 2, 3, 4, 5. (4 marks)



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Answer 2 continued

Description	Marks
One mark for each line with correct arrow	1–3
While it is not essential that the energy level diagram be drawn to scale there should be some indication that candidates appreciate that as n increases the energy difference between levels gets smaller. Allow if this is obvious	1
	Total 4

(b) Which value of wavelength from the list above corresponds to the transition with the largest energy difference? Explain your answer. (2 marks)

Description	Marks
From $E=\frac{hc}{\lambda}$, largest E corresponds to lowest λ,	1
So $\lambda = 4.40 \times 10^{-7}$ m.	1
	Total 2

(c) The n = 2 level has an energy of -3.4 eV. The photon with wavelength 4.9×10^{-7} m corresponds to the transition between the n = 4 and n = 2 energy levels. Calculate the energy of the n = 4 energy level in eV. (3 marks)

Description	Marks
E of photon = $hc/\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{4.9 \times 10^{-7} \times 1.6 \times 10^{-19}}$ = 2.53 eV	1-2
$E_{n=4}$ = -3.4 ev + 2.5 eV = -0.9 eV	1
	Total 3

The following passage describes how the redshift of a star or galaxy can be measured:

'To determine the redshift, the absorption or emission spectra of the astronomical object are looked for. These can be compared with known spectra of various elements and compounds existing on Earth. If the same pattern of lines is seen in a spectrum from a distant source but occurring at shifted wavelengths, it can be identified as originating from the same element or compound. If the same spectral line is identified in both spectra but at different wavelengths then the redshift can be calculated.'

Redshift is expressed in terms of a parameter z.

$$z = \frac{\lambda_{observed}}{\lambda_{earth}} - 1$$

The redshift of the galaxy 8C is z = 4.25.

(d) Calculate the wavelength of the n = 4 to n = 2 transition in hydrogen that would be observed by an astronomer studying the galaxy 8C. (2 marks)

Description	Marks
Rearrange equation above: $\lambda_{observed} = (z+1) \times \lambda_{earth}$	1
$\lambda_{obs} = (4.25+1) \times 4.9 \times 10^{-7}$ m $= 2.6 \times 10^{-6}$ m	1
	Total 2

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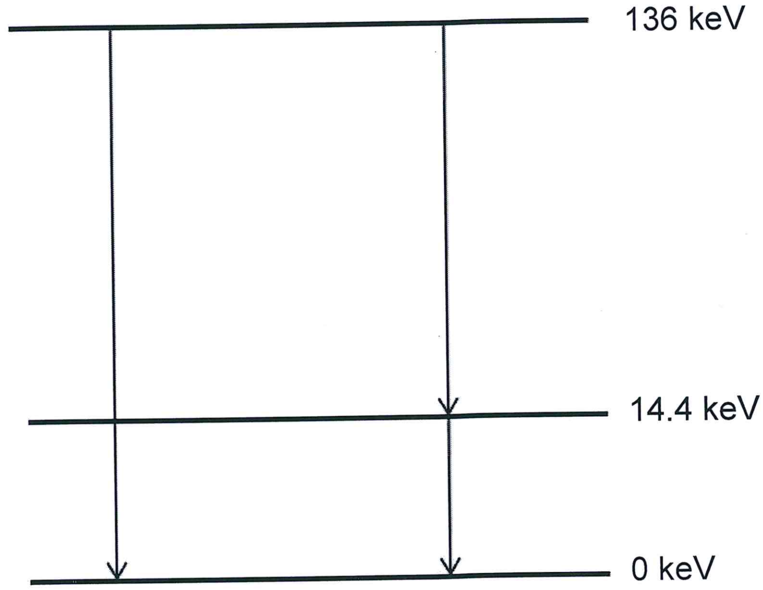
Answer 3 2011:1:6

(4 marks)

When a radioactive isotope undergoes gamma decay, a nucleus in an excited state decays to a lower energy state of the same isotope by the emission of a photon. This decay is similar to the emission of light when an electron in an atom moves from a higher energy level to a lower one. The isotope $^{57}_{26}Fe$ can decay to the ground state in the two ways shown on the energy level diagram below.

Calculate the wavelength of the photon emitted in the transition from the level with energy of 136 keV to the level with energy of 14.4 keV.



Description	Marks
Energy of photon 136 keV – 14.4 keV = 121.6 keV	1
Convert to J 121.6 keV × 1000 × 1.6 ×10^{-19} C = 1.95 × 10^{-14}J	1
$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.95\times10^{-14}}$	1
λ = 1.02 × 10^{-11} m	1
	Total 4

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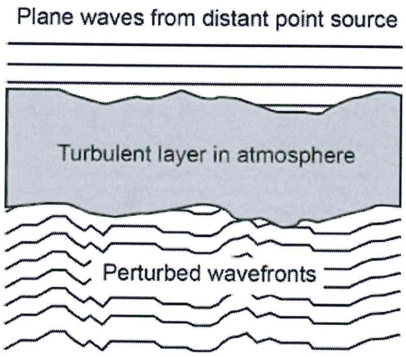
Answer 4 2011:3:23

(17 marks)

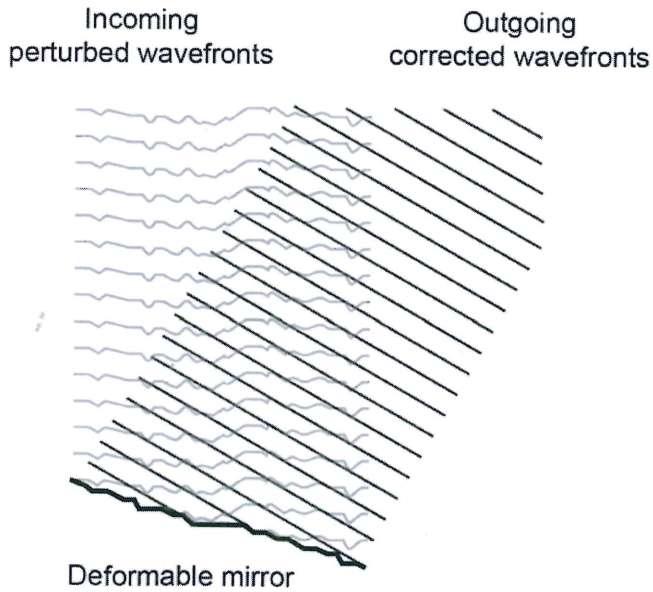
Adaptive Optics and Laser Guide Star

Telescopes with very large mirrors can gather a lot of light to allow viewing of dim, distant astronomical objects. As light waves pass through the atmosphere, tiny variations in the refractive index of the atmospheric gases distort the light's path, causing stars to appear to change position and twinkle. Large-diameter mirrors with fixed focal points thus suffer from image distortion when the position of an astronomical object seems to be in many different places when viewed from different places on the mirror.



Optical wave fronts from an astronomical object may be distorted by a layer of turbulence in the atmosphere. The amount of distortion has been exaggerated.

Adaptive optics is a technology used to improve the performance of large telescopes by reducing the effect of wavefront distortions caused by atmospheric distortion. Adaptive optics works by measuring the distortions in a wavefront and compensating for them with a deformable mirror. This requires a wavefront reference source to allow the telescope to correct the distortion of light caused by turbulence in the atmosphere. Turbulence changes the refractive index of the atmosphere in unpredictable ways. Monitoring the apparent motions of a bright star with known optical characteristics can provide a reference for adaptive optics. When the atmosphere's effects are subtracted, using a deformable tip-tilt mirror, the astronomical image produced is steady and clear.



A deformable mirror can correct distorted incoming wavefronts.

Many parts of the sky lack stars bright enough to use for judging atmospheric conditions. This limits the effectiveness of adaptive optics that use natural guide stars. A laser guide star is an artificial star-like light source created by shining a laser into the upper atmosphere. Such an artificial 'star' can be positioned anywhere that the astronomer wishes to observe, allowing any part of the sky to be viewed using adaptive optics.

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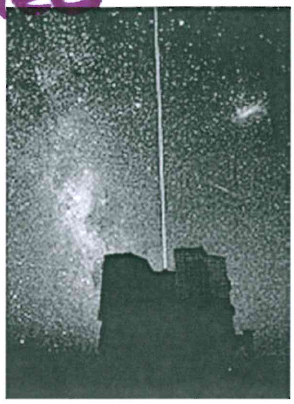
Answer 4 continued



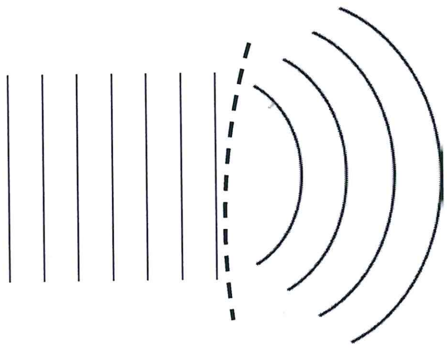
The bright line is a laser beam visible only because of atmospheric scattering.

A 'sodium beacon' is one type of laser guide star. It is created by shining a laser tuned to 589 nm (nanometres) into the upper atmosphere, exciting a naturally-occurring layer of sodium atoms at an altitude of about 90 km. The excited sodium atoms quickly decay, re-emitting the 589 nm light and giving the appearance of a glowing star.

Often, the laser is pulsed and the light from the laser guide star is measured a very short time after the pulse is emitted. This eliminates errors from scattered light at ground level, so that only light that has travelled down from the sodium layer is actually detected. The light returning from the sodium beacon, having travelled through most of the atmosphere, appears to have moved around in the sky in the same way as the light from astronomical objects.

(a) The following diagram shows light wavefronts moving from more dense air, where it moves slower, to less dense air, where it travels faster. Complete the diagram by sketching four more wave fronts in the less dense air.

(2 marks)



More dense 'slow' air

Less dense 'fast' air

Description	Marks
Wave fronts are spread out (further apart) (wavelength is larger)	1
Wave paths diverge/curved wavefronts	1
	Total 2

(b) Calculate the time taken for a pulse from a laser to reach the sodium layer and for the re-emitted light to return to the Earth's surface. Assume that the decay time of excited sodium atoms is negligible.

(3 marks)

Description	Marks
Data from article s = 90 km × 2 = 1.8×10^5 m	1
$c = 3 \times 10^8$ m s^{-1} $t = \frac{s}{v} = 1.8 \times 10^5 / 3 \times 10^8$	1
$t = 6.0 \times 10^{-4}$ s	1
	Total 3

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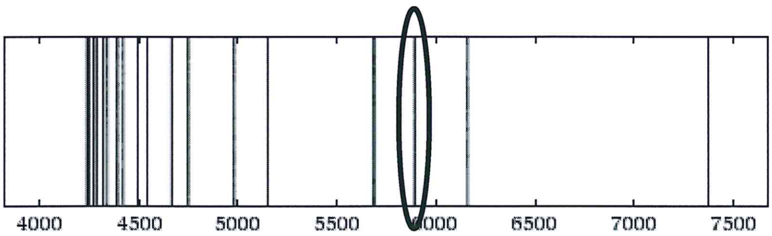
Answer 4 continued

(c) Calculate the energy in electron volts of a photon of light produced by the sodium beacon laser. (3 marks)

Description	Marks
$E = hc/\lambda = 6.63 \times 10^{-34} \times 3 \times 10^{8}/589 \times 10^{-9} = 3.38 \times 10^{-19}$	1
$E = 3.38 \times 10^{-19} \div 1.6 \times 10^{-19}$	1
$= 2.11 \text{eV}$	1
	Total 3

(d) When white light is shone through a gas consisting of sodium atoms and then passed through a prism, the white light's visible spectrum has several dark lines appear, as shown below. The scale is in angstroms ($\times 10^{-10}$ m). (4 marks)



(i) What type of spectrum is this considered to be? Line absorption

(ii) Circle the part of the spectrum that corresponds to the light emitted by a sodium beacon laser.

(iii) Astronomers observe light that has passed through gases, such as in a nebula (a gas cloud in space) or a planet's atmosphere. Explain how the characteristics of this light are used to determine the composition of the gases.

	Description	Marks
(i)	line absorption	1
(ii)	line at 5890 angstroms circled	1
(iii)	for a photon to be absorbed, the photon's energy must correspond to an energy level difference of the atom	1
	each element has a unique set of energy level differences, identifying the gas	1
		Total 4

Fluorescent angiography is a technique for examining the circulation of blood in the retina of the eye using a dye-tracing method. It involves the injection of sodium fluorescein, which circulates through the whole body, including the eye. The eye is then illuminated using blue light of wavelength 490 nm. The sodium fluorescein fluoresces, emitting yellow-green light that is photographed to create an angiogram.

(e) Using the energy level diagrams below, determine and draw on the diagrams the photon absorption and emission transitions for:

A the sodium beacon laser guide star

and

B the fluorescent angiography. You must show the calculations used for determining the absorption transition.

The energy level diagrams are simplified. A sodium atom has many energy level transitions available and therefore not all energy levels are shown. (5 marks)

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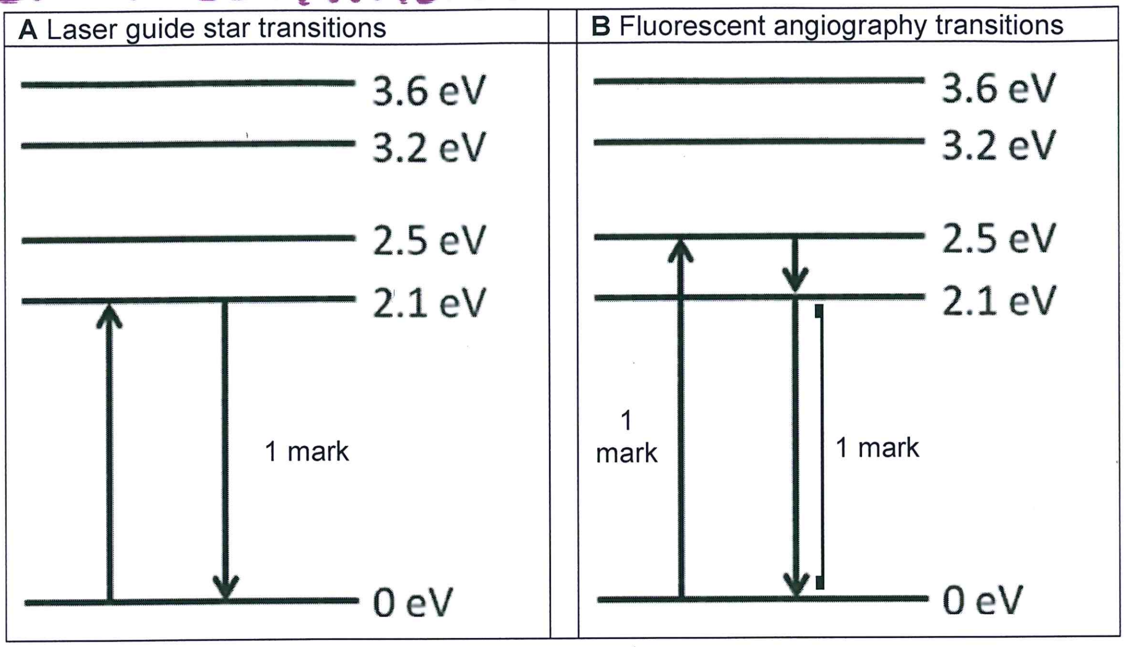
Answer 4 continued



Description	Marks
Diagram A	
Line upwards from 0 eV to 2.1 eV then return 2.1 eV to 0 eV	1
Diagram B	
$E = hc/\lambda = 6.63 \times 10^{-34} \times 3 \times 10^{8}/490 \times 10^{-9} = 4.06 \times 10^{-19}$ J	1
$E = 4.06 \times 10^{-19}$ J $/ 1.6 \times 10^{-19} = 2.53$ eV	1
Line upwards from 0 eV to 2.5 eV	1
Line downwards from 2.5 eV to 2.1 eV, then 2.1 eV to 0 eV (or any two smaller steps if calculation not present)	1
	Total 5

Answer 5 2013:1:7

(4 marks)

The element helium gets its name from the Greek sun-god 'Helios'. This is because helium is the only element to have been discovered in the Sun before it was isolated on the Earth. Helium was identified from unknown lines in the solar spectrum.

With reference to the discovery of helium, explain the origin and significance of lines in the solar spectrum.

Description	Marks
The sun emits a continuous spectrum with absorption lines	1
The absorption lines are specific to orbital energy differences of atoms/molecules	1
Atoms absorb energy and re emit in all directions creating dark lines (scattered).	1
The absorption lines (Fraunhofer Lines) could all be accounted for by known elements except for a set of 'unknown' lines which must be from a new (unknown) element... this element was named helium prior to its detection of Earth.	1
Total	**4**

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Answer 6 2013:3:20

(16 marks)

How plasma displays work

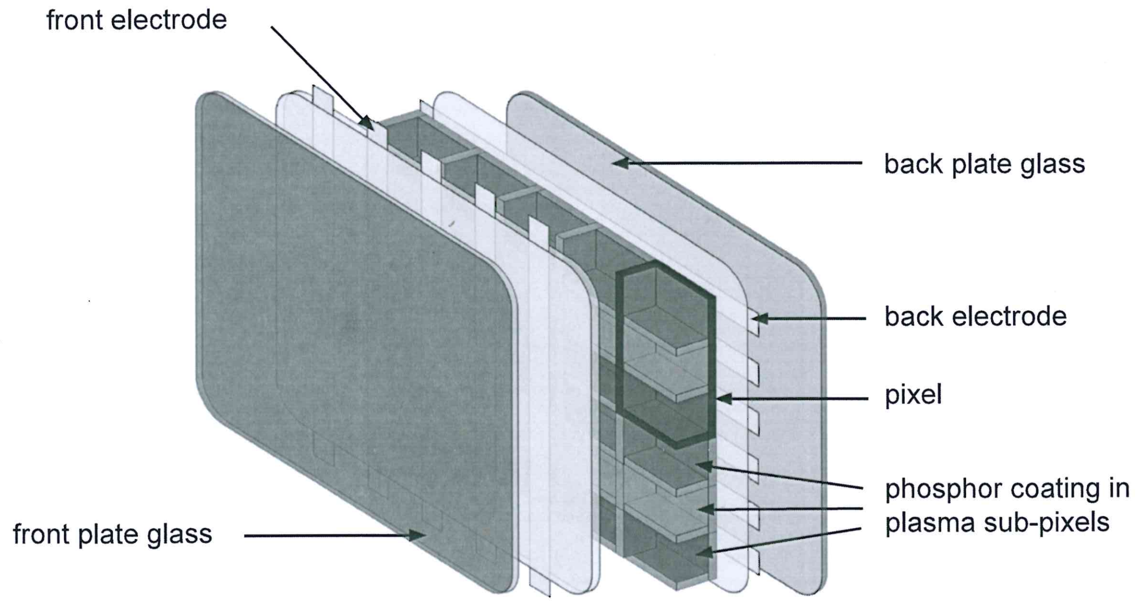
A plasma display panel typically comprises of millions of tiny compartments called 'sub-pixels' between two glass panels. Each sub-pixel contains a mixture of unreactive gases, mostly neon and xenon. These gases have electron energy levels suitable for the emission of ultraviolet (UV) photons when their atoms are excited. This occurs when a potential difference across a sub-pixel creates a current in the gas.

As electrons move through a sub-pixel, some strike gas atoms, causing the gas to emit UV photons. The UV photons then strike a phosphor layer that coats the inside of the sub-pixel, and the phosphor molecules fluoresce. An outer-orbit electron in a phosphor molecule momentarily moves from a stable lower-energy state to an unstable higher-energy state. The excited electron then returns to the stable state by a series of decays, emitting photons of lower energy than UV. These lower-energy photons are about 60% infrared and 40% visible.

Different phosphors produce different colours of visible light. A group of three sub-pixels, each of which produces one of the primary colours of visible light (red, green and blue), makes up a pixel in a plasma display.

The electrodes are strips of electrically-conducting material that also lie between the glass plates, in front of or behind the sub-pixels.

A plasma display panel



Control circuitry creates a voltage difference between the electrodes at the front and back of a sub-pixel. This sends a pulse of current through the sub-pixel. Some of the gas atoms in the sub-pixel become ionised, creating an electrically-conducting plasma consisting of atoms, free electrons and ions.

By varying the voltages across the sub-pixels, the control circuitry increases or decreases the intensity of each sub-pixel colour. The hundreds of different possible combinations of red, green and blue intensities allow the plasma screen to produce perceived colours across the entire visible spectrum.

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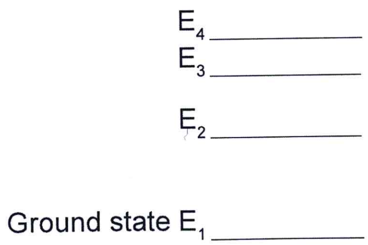
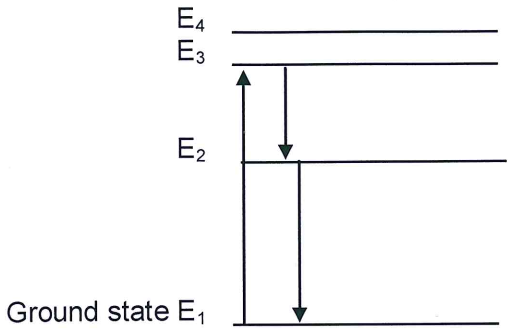
Chapter 8·1 - Spectra
Answer 6 continued

(a) Use the simplified sketch of an atom's energy levels below to explain how a phosphor produces visible light. (3 marks)





Description	Marks
Uses diagram showing upward(absorption) and downward (emission) transitions	1
Upward (absorption) has larger energy/frequency than downward (emission) transition(s)	1
Specifies absorption is non-visible while emission is visible	1
Total	**3**

(b) Explain how plasma screens are able to create different colours of light by varying the potential difference across the individual cells. (3 marks)

Description	Marks
There are different cells of red, green and blue.	1
Which are combined in different intensities to form the different colours.	1
Changing a cell's potential difference changes the intensity	1
Total	**3**

(c) The first ionisation energy of xenon is 1.94×10^{-18} J. Determine the minimum speed in m s^{-1} of an electron that can ionise the xenon atom through collision. (3 marks)

Description	Marks
$E=\frac{1}{2}mv^2$ $v=\sqrt{(2E/m)}$	1
$v=\sqrt{(2\times1.94\times10^{-18}/9.11\times10^{-31})}$	1
$v=2.06\times10^{6}$ m s^{-1}	1
Total	**3**

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Chapter 8.1 - Spectra
Answer 6 continued

(d) Given that one ampere is equivalent to a charge transfer rate of one coulomb per second, determine the current flow needed in a plasma sub-pixel to generate 1.00 μW of red light at a frequency of 4.00×10^{14} Hz. (7 marks)

Description	Marks
$E=hf=6.63 \times 10^{-34} \times 4.00 \times 10^{14}$ Hz	1
$E=2.65 \times 10^{-19}$ J per photon	1
$1 \mu W = 1\times10^{-6}$ J s^{-1} $1\times10^{-6}/2.65\times10^{-19}=3.77 \times 10^{12}$ photon needed	1
Assuming 1 electron per collision, then 3.77×10^{12} electrons are needed per second	1
$q = 1.6 \times 10^{-19} \times 3.77\times10^{12} = 6.03 \times10^{-7}$ C	1
$I = qt = 6.03 \times 10^{-7} \times 1 = 6.03 \times 10^{-7}$	1
Efficiency is stated at 40% so current should allow for this $I = 6.03 \times 10^{-7}/.4 = 1.50 \times 10^{-6}$ A	1
Total	**7**

NB: Minimum value assumed for 100% collision rate. Larger current value will result if a decreased collision rate is assumed. Must be stated.

Answer 7 2014:1:6

(4 marks)

The images below show hydrogen spectra.

Image 1: Bright lines on a black background.

Image 2: Dark lines on a continuous spectrum.

For each, name the type of spectrum and describe how it is created.

Description	Marks
Image 1: (Line) emission spectrum	1
Created by the emission of photons from excited electrons	1
Image 2: (Line) absorption spectrum	1
Electrons absorb certain frequencies of light, leaving missing frequencies in an otherwise continuous spectrum	1
Total	**4**