TOPIC 27 Line Spectra

1 The table below gives the energies of the six lowest levels of the hydrogen atom:

Level n	1	2	3
Energy/J	-2.2×10^{-18}	-5.3×10^{-19}	-2.4×10^{-19}

Level n	4	5	6
Energy/J	-1.3×10^{-19}	-8.0×10^{-20}	-6.0×10^{-20}

When an electron changes levels from $n = 6$ to $n = 1$, the spectral line emitted has a wavelength 9.1×10^{-8} m. The wavelength of the spectral line emitted by the transition from $n = 4$ to $n = 3$ is approximately

A 4.5×10^{-10} m **D** 1.8×10^{-4} m
B 4.5×10^{-8} m **E** 1.6×10^{-4} m
C 1.8×10^{-6} m

J77/II/34

2 A fluorescent pigment has a characteristic wavelength at which it fluoresces. It is excited only by absorbing radiation of wavelength shorter than the characteristic wavelength. A red fluorescent pigment will not be excited by

A radiation from a filament at a high temperature.
B light from a sodium discharge tube.
C monochromatic blue light.
D infra red radiation.
E sunlight.

J78/II/28

3 An atom emits a spectral line of wavelength λ when an electron makes a transition between levels of energy E_1 and E_2.

Which expression correctly relates λ, E_1 and E_2?

A $\lambda = \frac{h}{c}(E_1 - E_2)$ **C** $\lambda = \frac{c}{h(E_1 - E_2)}$

B $\lambda = ch(E_1 - E_2)$ **D** $\lambda = \frac{ch}{E_1 - E_2}$

J79/II/37; J87/I/29; J97/I/28

4 The energies of four levels of the hydrogen atom are

level P, −13.60 eV; level Q, −3.40 eV; level R, −1.50 eV; level S, −0.85 eV.

Taking the Planck constant as 6.63×10^{-34} J s, the electron charge as -1.60×10^{-19} C and the speed of light as 3.00×10^{8} m s^{-1}; a spectral line of 488 nm could result from an electron transition between levels

A Q and P **D** R and Q
B R and P **E** S and Q
C S and P

N79/II/35

5 For advertising or other eye-catching purposes, fluorescent paint, which appears to glow in daylight, is often used. The glow occurs because

A ultraviolet light is absorbed by the paint and some of the absorbed energy is re-emitted as visible light.
B the paint is heated by the daylight and gives out visible radiation.
C the long wavelength infra-red radiation in sunlight causes some colours to become brighter.
D light falls on the paint from many directions but is diffracted only in the direction of the eye.
E the pigment of the paint is radioactive and radioactive emission is accompanied by light in the visible region.

J80/II/9

6 The line spectrum of hydrogen includes no X-ray frequencies because

A hydrogen nuclei do not contain neutrons.
B hydrogen cannot be raised to a sufficiently high temperature.
C the cut-off frequency cannot be reached.
D there are too few electronic energy levels in the hydrogen atom.
E the ionisation energy of a hydrogen atom is too low.

J80/II/38

7 The energy levels of an electron in a hydrogen atom are given by

$E = \frac{-13.6}{n^2}$ eV, where $n = 1, 2, 3, \ldots$

The energy required to excite an electron from the ground state to the first excited state is

A 3.4 eV **C** 10.2 eV **E** 27.2 eV
B 4.5 eV **D** 13.6 eV

N80/II/36

8 Which of the following provides experimental evidence for discrete electron energy levels in atoms?

A the spectrum of a tungsten filament lamp
B the spectrum of a sodium discharge lamp
C the photoelectric effect
D the emission of β-particles by radioactive atoms
E the emission of γ-rays by radioactive atoms

J81/II/36; N85/I/28; J88/I/29

9 Electrons emitted by a hot filament pass down a tube containing hydrogen and are then collected by an anode which is maintained at a positive potential with respect to the filament. The gas near the anode is found to emit monochromatic ultra-violet radiation. The radiation is monochromatic because

A the nuclei emitting it are identical.
B the atoms emitting it each contain only one electron.
C the electrons gain only enough energy to raise the hydrogen atoms to their first excited state.
D the potential difference between the filament and the anode is less than the ionisation potential of hydrogen.
E the energy of the electrons is less than the energy of a quantum of light.

N81/II/33

10 When a parallel beam of white light passes through a metal vapour, dark lines appear in the spectrum of the emergent light. This is principally because energy is absorbed and

- **A** is not re-radiated at all.
- **B** is re-radiated as infra-red.,
- **C** is re-radiated as ultra-violet.
- **D** is re-radiated gradually over a long period of time.
- **E** is re-radiated uniformly in all directions. J82/II/34

11 In Fig. 1 below, E_1 to E_6 represent some of the energy levels of an electron in the hydrogen atom.

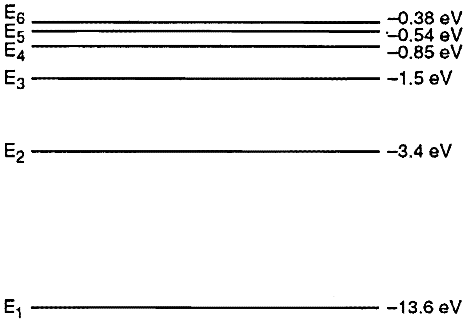


Fig. 1

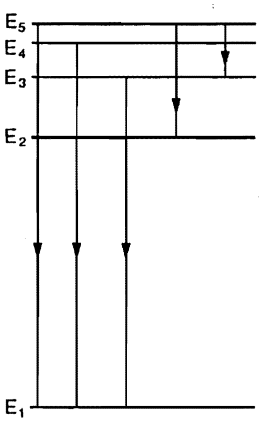
Which one of the following transitions produces a photon of wavelength in the ultra-violet region of the electro-magnetic spectrum?

[1 eV = 1.6×10^{-19} J.]

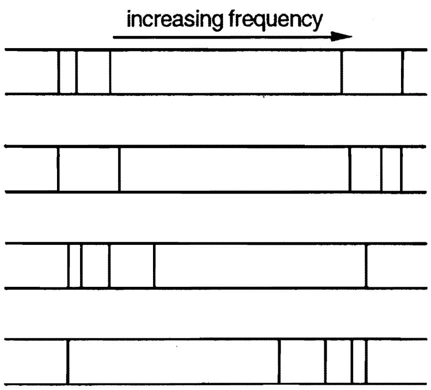
A $E_2 \rightarrow E_1$ **C** $E_4 \rightarrow E_3$ **E** $E_6 \rightarrow E_5$

B $E_3 \rightarrow E_2$ **D** $E_5 \rightarrow E_4$ J84/II/39; N82/II/34

12 The diagram shows five energy levels of an atom. Five possible transitions between the levels are indicated. Each transition produces a photon of definite energy and frequency.



Which spectrum corresponds most closely to the transitions shown?



J83/II/35; N85/I/29; N97/I/28

13 Transitions between three energy levels in a particular atom give rise to three spectral lines of wavelengths, in order of increasing magnitude, λ_1, λ_2 and λ_3. Which of the following equations correctly relates λ_1, λ_2 and λ_3?

- **A** $\frac{1}{\lambda_1} = \frac{1}{\lambda_2} + \frac{1}{\lambda_3}$
- **B** $\frac{1}{\lambda_1} = \frac{1}{\lambda_3} - \frac{1}{\lambda_2}$
- **C** $\frac{1}{\lambda_1} = \frac{1}{\lambda_2} - \frac{1}{\lambda_3}$
- **D** $\lambda_1 = \lambda_2 - \lambda_3$
- **E** $\lambda_1 = \lambda_3 - \lambda_2$ N89/I/30; N87/I/28; N83/II/33

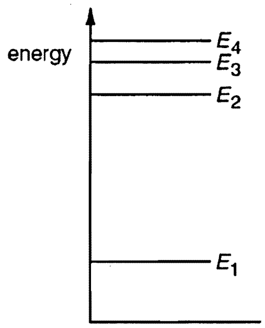
14 The minimum energy to ionise an atom is the energy required to

- **A** add one electron to the atom.
- **B** excite the atom from its ground state to its first excited state.
- **C** remove one outermost electron from the atom.
- **D** remove one innermost electron from the atom.
- **E** remove all the electrons from the atom. J84/II/33

15 The existence of energy levels within atoms can be demonstrated directly by observing that

- **A** atoms can emit line spectra.
- **B** photoelectrons are only emitted for wavelengths greater than a critical wavelength.
- **C** some α-particles are reflected back through very large angles by atoms in a solid.
- **D** X-rays with frequencies up to a certain maximum are emitted by a target.
- **E** atoms in a solid diffract electrons in the same way as crystals diffract X-rays. N84/II/33

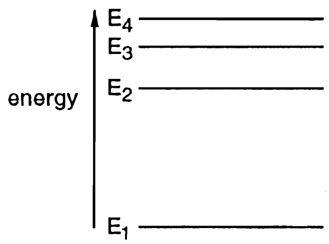
16 The diagram below represents, drawn to scale, the energy levels for an electron in a certain atom.



The transition from E_3 to E_1 produces a green line. What transition could give rise to a red line?

- **A** E_4 to E_3
- **B** E_4 to E_2
- **C** E_4 to E_1
- **D** E_3 to E_2
- **E** E_2 to E_1 J85/I/29

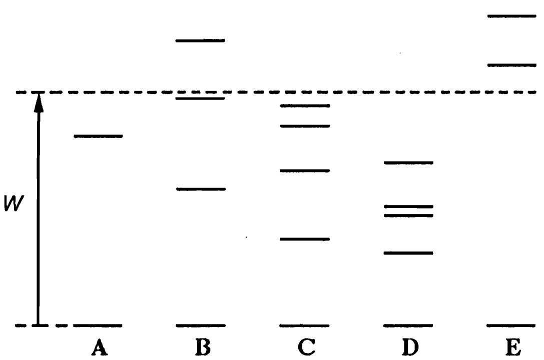
17 The diagram below represents in simplified form some of the lower energy levels of the hydrogen atom.



If the transition of an electron from E_4 to E_2 were associated with the emission of blue light, which one of the following transitions could be associated with the emission of red light?

A E_4 to E_1
B E_3 to E_1
C E_3 to E_2
D E_1 to E_3
E E_2 to E_3 J86/I/28

18 The diagram shows the electron energy levels, referred to the ground state (the lowest possible energy) as zero, for five different isolated atoms. Which atom can produce radiation of the shortest wavelength when atoms in the ground state are bombarded with electrons of energy W?



J89/I/29

19 White light from a tungsten filament lamp is passed through sodium vapour and viewed through a diffraction grating.

Which of the following best describes the spectrum which would be seen?

A coloured lines on a black background
B coloured lines on a white background
C dark lines on a coloured background
D dark lines on a white background N90/I/28; J94/I/28

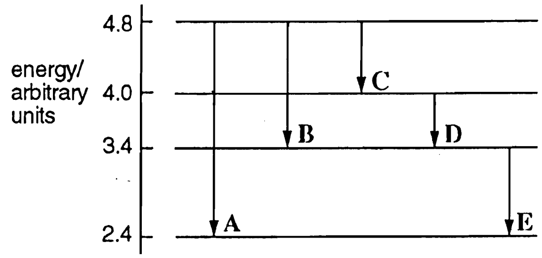
20 Listed below are five phenomena connected with photons and/or charged particles:

1 alpha-particle emission
2 beta-particle emission
3 line emission spectra
4 line absorption spectra
5 electron diffraction

Which of these phenomena give direct evidence for the existence of discrete electronic energy levels in atoms?

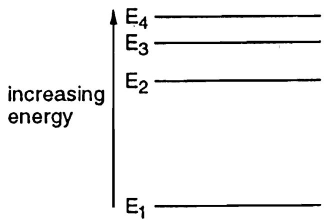
A 1 and 5 only
B 2 and 3 only
C 3 and 4 only
D 2, 3, 4 and 5 only
E 1, 2, 3, 4 and 5 J91/I/28

21 The diagram represents electron energy levels in an atom. The arrows show five possible electron transitions.



Which of these electron transitions corresponds to the shortest wavelength of radiation emitted? N91/I/29

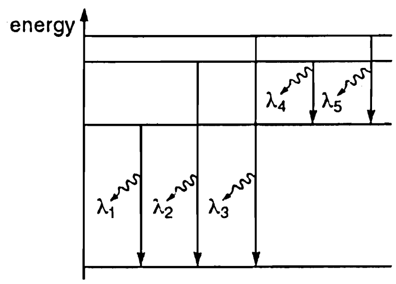
22 The diagram represents in simplified form some of the energy levels of the hydrogen atom. The energy axis has a linear scale.



If the transition of an electron from E_4 to E_2 were associated with the emission of blue light, which transition could be associated with the absorption of red light?

A E_4 to E_1
B E_3 to E_2
C E_2 to E_3
D E_1 to E_4 N94/I/28

23 An energy level diagram for an atom is shown drawn to scale. The electron transitions give rise to the emission of a spectrum of lines of wavelength λ_1, λ_2, λ_3, λ_4, λ_5.

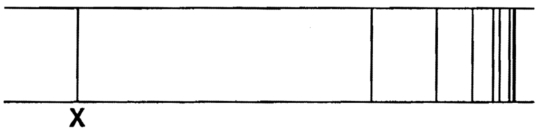


What can be deduced from this diagram?

A $\lambda_1 > \lambda_2$
B $\lambda_3 = \lambda_4 + \lambda_5$
C λ_4 is the shortest of the five wavelengths.
D The transition corresponding to wavelength λ_3 represents the ionisation of the atom.

J95/I/28; N2000/I/28

24 The diagram shows part of a typical line emission spectrum. This spectrum extends through the visible region of the electromagnetic spectrum into the ultraviolet region.



Which statement is true for emission line **X** of the spectrum?

A It has the longest wavelength and is at the ultraviolet end of the spectrum.
B It has the highest frequency and is at the ultraviolet end of the spectrum.
C It has the lowest frequency and is at the red end of the spectrum.
D It has the shortest wavelength and is at the red end of the spectrum. N95/I/27

25 An atom makes a transition from a state of energy E_2 to one of lower energy E_1.

Which of the following gives the wavelength of the radiation emitted, in terms of the Planck constant h and the speed of light c?

A $\dfrac{E_2 - E_1}{hc}$ **C** $\dfrac{hc}{E_2 - E_1}$

B $\dfrac{hc}{E_2} - \dfrac{hc}{E_1}$ **D** $\dfrac{c}{h(E_2 - E_1)}$ N99/I/28

26 Fig. 2 represents the energy levels of the four lowest states of the hydrogen atom. The energies are in units of electron-volts.

(a) Calculate the longest wavelength which might be emitted by a spectral transition between any pair of these four levels.

(b) Determine the total number of different spectral lines, which might be detected in the emission spectrum of atomic hydrogen, due to transitions between these four states.

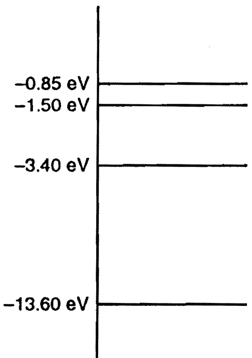


Fig. 2

[Charge on the electron = -1.6×10^{-19} C; the Planck constant = 6.6×10^{-34} J s; speed of light = 3.0×10^{8} m s^{-1}.] J76/I/9

27 Draw a sketch showing the energy levels of the electron in a hydrogen atom. Indicate on your diagram *(a)* the ground state of the atom, *(b)* the first excited state, *(c)* the ionisation energy. How may information about the energy levels of atoms be obtained? J80/I/10

28 'The first excitation energy of the hydrogen atom is 10.2 eV.' Explain what is meant by this statement. Find the speed of the slowest electron that could cause excitation of a hydrogen atom. J82/I/11

29 A sodium vapour lamp is set up in front of a white screen and between the two is a bunsen burner. Describe and explain what will be seen on the screen if a platinum wire, having been dipped into a solution of sodium chloride, is held in the bunsen flame. N85/III/3

30 Describe the appearance of an *absorption* spectrum. J86/III/3

31 State how you would produce *(a)* a line spectrum and *(b)* a continuous spectrum in the laboratory. Describe the appearance of each spectrum when viewed through a grating spectrometer. N86/III/3

32 Fig. 3 shows three of the electronic energy levels of an atom. What are the frequencies of electromagnetic radiation which can result from transitions between these levels?

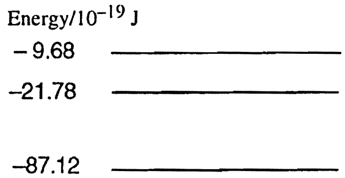


Fig. 3

State the region of the electromagnetic spectrum in which the emitted radiation lies. [6] N88/II/7

33 Fig. 4 illustrates some of the electron energy levels in an isolated atom of lithium. The energies of the levels are given in electron-volts (eV).

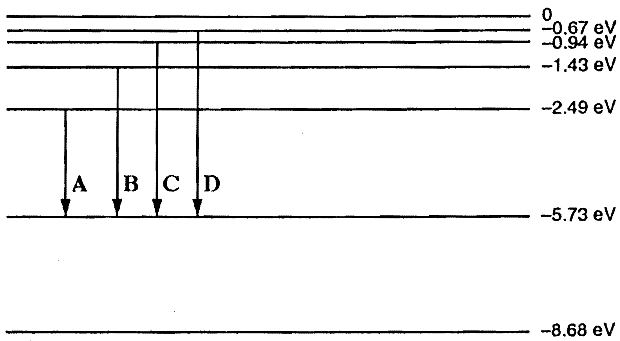


Fig. 4

(a) The outer electron of a lithium atom is in the lowest energy level shown. How many joules of energy are required to remove this electron from the atom? [1]

(b) (i) Which of the transitions **A**, **B**, **C** or **D** would lead to the emission of radiation of the shortest wavelength?

(ii) Calculate the wavelength of this radiation.

(iii) State the region of the electromagnetic spectrum in which this radiation lies. [4]

(c) Sketch the appearance of the spectrum which these four transitions produce. [1]

(d) On Fig. 4, draw four transitions of greater energy change which give rise to another set of wavelengths. [2]

(e) The work function energy of lithium differs from the energy required to remove the outer electron from an isolated lithium atom. Suggest why this is so. [2]

J96/II/7

34 Fig. 5 shows four energy levels for electrons in a hydrogen atom. It shows one transition, which results in the emission of light of wavelength 486 nm.

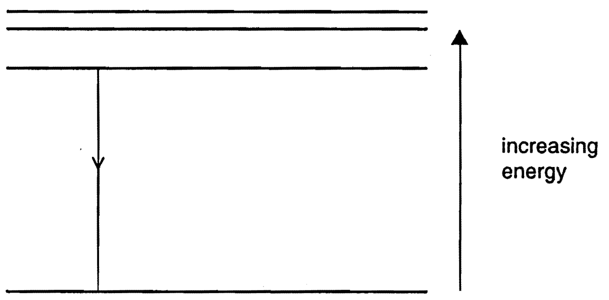


Fig. 5

(a) On Fig. 5, draw arrows to show

(i) another transition which results in the emission of light of shorter wavelength (label this transition L),

(ii) a transition which results in the emission of infra-red radiation (label this transition R),

(iii) a transition which results from absorption (label this transition A). [4]

(b) Calculate the energy change which an electron has to undergo in order to produce light of wavelength 486 nm.

energy change = ... J[4]

J99/II/7

Long Questions

35 Summarise the experimental evidence that suggests the existence of energy levels in atoms.

Fig. 6 below represents five of the lowest energy levels of the hydrogen atom.

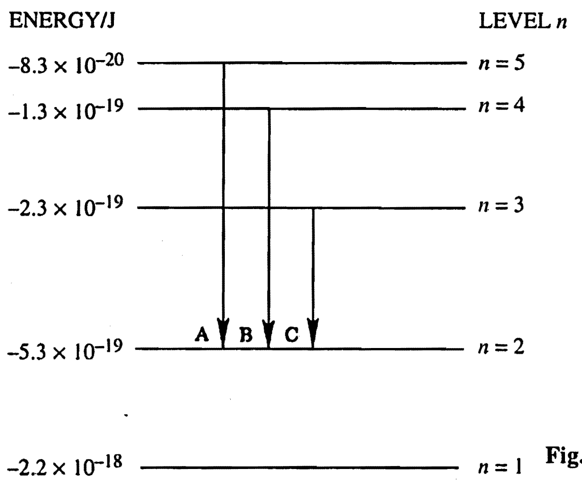


Fig. 6

Calculate the wavelengths associated with the transitions A, B, and C. Show that these wavelengths λ fit the formula for the Balmer series:

$$1/\lambda = R\,(1/2^2 - 1/n^2)\,,$$

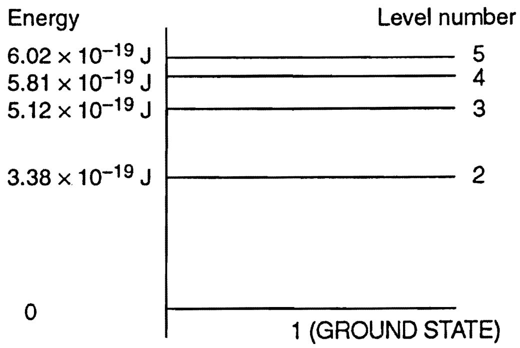
where R is a constant and n is the quantum number of the upper level involved in the transition. Deduce a value for R.

Calculate the shortest wavelength associated with the Balmer series quoted above and explain which transition is responsible for its emission.

[The Planck constant, $h = 6.6 \times 10^{-34}$ J s; the speed of light, $c = 3.0 \times 10^{8}$ m s^{-1}.]

N78/III/5

36 The diagram is a simplified representation of the 5 lowest energy levels of the outermost electron in the sodium atom.



(a) Considering transitions between only these levels,

(i) which spectral transition has the shortest wavelength (give your answer in terms of level numbers),

(ii) how many spectral emission lines might be produced by transitions among these levels?

(b) If the sodium atoms are initially in the ground state, how many absorption lines might be detected?

(c) Cool sodium vapour at low pressure is bombarded with electrons of kinetic energy E.

Which transitions would you expect to observe if E has the value

(i) 3×10^{-19} J, (ii) 4×10^{-19} J,

(iii) 5.5×10^{-19} J?

In practice, the highest level inferred from observations of single electron transitions in the sodium spectrum is 8.21×10^{-19} J. Explain the significance of this value, and calculate the range of potential differences which would accelerate bombarding electrons to produce spectral line emission, but no free electrons.

In fact, level 2 consists of a pair of closely spaced levels. Transitions from them to another level give rise to the sodium "D-lines" of wavelengths 589.0 nm and 589.6 nm. Calculate the energy difference between the two levels of the closely spaced pair and identify the other level involved.

N84/III/6

37 What is a photon? Show that the energy E of a photon and its wavelength λ are related by $E\lambda = 1.99 \times 10^{-16}$ J nm.

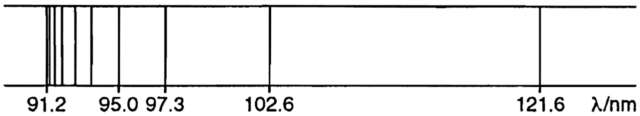


Fig. 7

Fig. 7 represents part of the emission spectrum of atomic hydrogen. It contains a series of lines, the wavelengths of some of which are marked. There are no lines in the series with wavelengths less than 91.2 nm.

(a) In which region of the electromagnetic spectrum are these lines?

(b) Using the relation between E and λ given above, find the photon energies equivalent to all the wavelengths marked.

(c) Use this information to map a partial energy level diagram for hydrogen. Show, and label clearly, the electron transitions responsible for the emission lines labelled in Fig. 7.

(d) Another line in the hydrogen spectrum occurs at a wavelength of 434.1 nm. Identify and label on your diagram the transition responsible for this line.

Emission spectra are often produced in the laboratory using a discharge lamp containing the gas to be investigated. Explain the physical processes occurring within such a lamp which lead to the excitation of the gas and the emission of light. J85/II/12

38 Name the phenomena which lead to the belief that light behaves like *(a)* a wave, *(b)* a stream of particles (photons).

Sketch a simple energy level diagram for a one-electron atom, and use it to explain what is meant by the terms *ground state, ionisation energy, excitation energies.*

The ionisation energy of hydrogen is 2.2×10^{-18} J. In the process of *photoionisation*, a photon interacts with the atom causing the ejection of the electron. Use the principle of conservation of energy to find the kinetic energy of the emitted electron if the incident radiation is of wavelength 63 nm.

Another process in which electron ejection takes place is *ionisation by collision.* If two hydrogen atoms, each moving with speed v, make a head-on inelastic collision, it is possible that one of the atoms may become ionised. Find v_{min}, the minimum speed for this to occur.

(Mass of hydrogen atom = 1.7×10^{-27} kg.) J87/II/13

39 *(a)* What is the meaning of each word as used in the term *line emission spectrum*? [3]

(b) Describe how you would carry out an experiment to find the wavelength of light of one of the lines in the hydrogen emission spectrum. [7]

(c) The measured wavelengths, λ_m, of selected lines in the hydrogen spectrum are given empirically by

$$\frac{1}{\lambda_m} = R\left(\frac{1}{4} - \frac{1}{m^2}\right),$$

where R is a constant and has the value 1.097×10^7 m^{-1} and m is an integer taking the values 3, 4, 5 ....., etc.

(i) Calculate the value of the wavelength when $m = 4$. [2]

(ii) Calculate the minimum wavelength given by this equation. [3]

(iii) Draw a diagram showing the approximate positions of the lines on a horizontal axis of wavelength. Mark the two values you have already calculated and also mark the red and the violet ends of the spectrum. [5]

(iv) Explain why it is that although there is an infinite number of lines in this spectrum, the spectrum is nevertheless seen as a line spectrum. [2]

J88/II/12

40 *(c)* **Figure 8** shows four energy levels A, B, C and D within an atom and an electron transition from level A to level C which results in the emission of a photon of light.

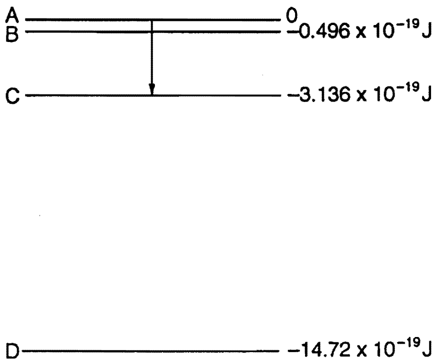


Fig. 8

(i) Show on a copy of the diagram all the other possible transitions between these four levels which result in photon emission.

(ii) Calculate the wavelength of the light emitted as a result of the electron transition from A to C.

(iii) Which other transition may result in visible light being emitted?

(iv) When a transition takes place from level A, B or C to level D, in which part of the electromagnetic spectrum will the radiation occur? [6]

(d) Explain how Fig. 8 can be used to account for absorption spectra. [2]

(e) When the spectrum of gamma radiation from a nucleus is examined, it is found that it too has a line emission spectrum. Suggest what can be deduced from this observation. [2]

J93/III/6 (part)

41 A hydrogen lamp is found to produce red light and blue light. The wavelengths of the light are 6.6×10^{-7} m and 4.9×10^{-7} m.

(a) (i) State which wavelength corresponds to the red light.

(ii) Explain why light of specific wavelengths is produced in the lamp.

(iii) Calculate the energy change in an atom associated with the emission of a photon of the red light. [5]

(c) The light from the hydrogen lamp is now directed normally on to a diffraction grating. The grating has 4.0×10^5 lines per metre.

(i) Calculate the angle between the red light and the blue light in the first order spectrum.

(ii) Hence suggest, with a reason, whether refraction at a glass-air surface or the use of a diffraction grating is preferable when studying the visible spectrum. [5]

(d) A metal surface has a work function energy of 1.80 eV.

By reference to

(i) your answer to *(a)*(iii), determine whether photo-emission of electrons from this surface is possible with red light,

(ii) the de Broglie equation, suggest whether light incident on the metal surface exerts a pressure on the surface. [6]

J98/III/6 (part)