Physics Factsheet

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Line Spectra

The purpose of this Factsheet is to explain the appearance, origin and significance of Line Spectra. Before studying the Factsheet, you should make sure that you are familiar with the idea of a spectrum from your GCSE course, and with the ideas of quantization of energy levels in an atom.

These ideas of Line Spectra are an important introduction to the understanding of the ideas of Factsheet 51 – The Electromagnetic Doppler Effect and the Expanding Universe.

Questions on line spectra are likely to occur on the PHY 4 Paper and also on PHY 6, the Synthesis Paper.

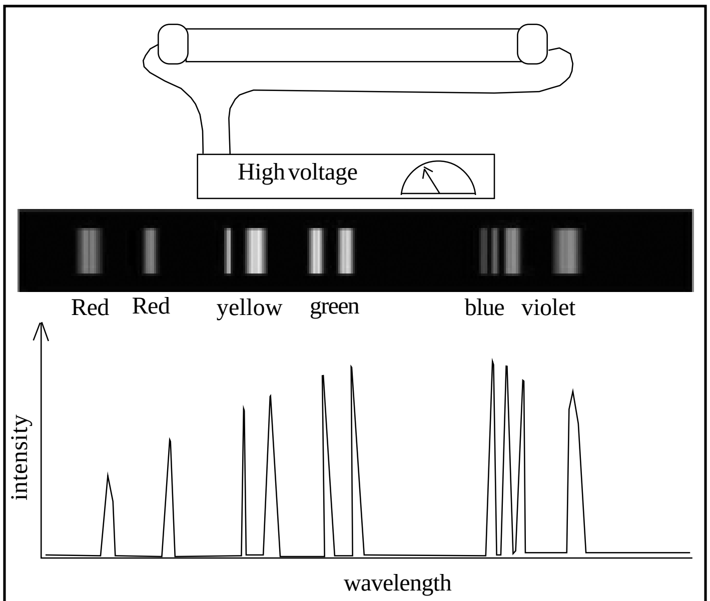
Appearance of Line Spectra

You will be familiar with the idea of a continuous spectrum, as produced by a prism. As the name suggests, line spectra consist not of a continuous band of different colours, but of discrete, separate lines. Each line is of a given frequency (wavelength), representative of a particular element.

A line spectrum consists of discrete lines, each typical of the element concered.

Observing Line Spectra in the laboratory

Emission line spectra may be observed in the laboratory by viewing a discharge tube with a diffraction grating. The tube contains a particular element, e.g., sodium, which, when operated at appropriate voltage, vaporises. The hot vapour emits light. The diffraction grating allows the spectrum to be viewed, rather like the prism does for a continuous spectrum.



Line spectra are observed by viewing a disharge tube with a diffraction grating

Origin of line spectra

An emission line spectrum is produced by a hot gaseous element. At high temperatures the electrons of the atoms are excited into higher energy levels. When they drop back to a lower level, the energy is emitted at a specific frequency (wavelength) depending on the energy gap between the levels, determined by the equation:

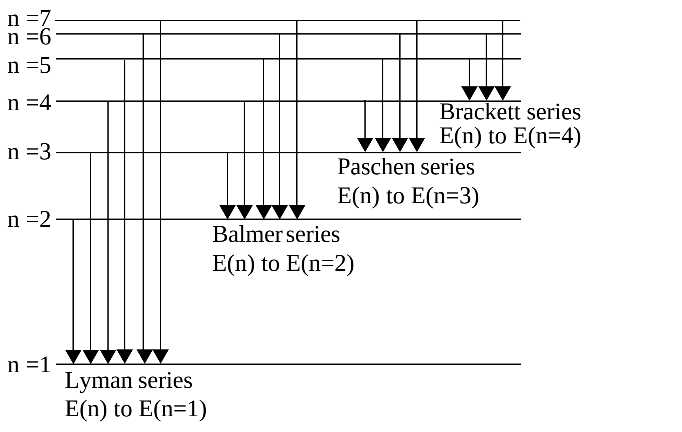
$\Delta E = hf$ *Where* ΔE = *energy level gap (J),*
f = *frequency of the observed spectral line (Hz)*
h = *Planck's constant.*

The observed lines are of frequency f, determined by the energy level gap and derived from the equation $\Delta E = hf$
N.B. *The energy levels may well be given in eV rather than J, so the figure must be multiplied by* 1.6×10^{-19} *to convert eV to J.*

Significance of Line spectra

The existence of line spectra provides evidence for the existence of quantized energy levels in the atom. Observations of the line spectra for hydrogen – the Lyman, Balmer, Paschen and Bracket Series enabled the energy levels of the single electron of the hydrogen atom to be established and agreement between experimental evidence and predictions of the theory is very good, thus giving confidence in the theory.

Electron transitions for the hydrogen atom



Calculations of the frequencies of lines in spectra

Example: The ground state for the electron in a hydrogen atom is –13.6 eV, the first excited state is –3.4eV. Calculate the frequency of the line in the spectrum representing this transition.

$\Delta E = hf$, so $(13.6 - 3.4) \times 1.6 \times 10^{-19} = 6.63 \times 10^{-34} \times f$

$$f = \frac{10.2 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = 2.46 \times 10^{15}\text{Hz}$$

Absorption Spectra

If white light (i.e. radiation of all frequencies – this term is used for the whole EM spectrum, not just visible light) passes through a cooler vapour, then the spectrum observed is of a continuous coloured spectrum with dark lines in the positions where the bright lines would have been in an emission spectrum. This is known as an absorption spectrum.

The absorption spectrum is formed as the vapour absorbs specific frequencies from white light. These frequencies are linked to the energies required for the electrons to jump into higher excited states. When the electrons later drop back into lower states, they emit radiation at these same frequencies. However this radiation is emitted in all directions, so the intensity in the orginal direction is reduced.

> *An absorption spectrum consists of dark lines where the bright lines would have been in an emission spectrum. It is formed when white light passes through a cooler vapour.*

Importance of absorption spectra

Observations of the absorption spectra of the light from distant stars has been used to identify which elements are present in the star. The white light passes through the cooler vapours of the outer layers of the star, forming the absorption spectrum. The positions of the dark lines can be compared with emission spectra of known elements on Earth.

> *Absorption spectra indicate what elements are present in stars.*

Doppler Shift of line spectra from distant stars.

Factsheet 51 deals with this important aspect of the use of line spectra. Known spectral lines are found to be shifted slightly towards lower frequencies (Red Shift). One explanation of this is that the source is moving away and the speed of recession can be calculated from the theory. This provides evidence to support the Big Bang theory of the origin of the Universe.

> *Red Shift of line spectra suggests that galaxies are moving away from each other, and this supports the Big Bang theory of the origin of the Universe.*

Exam Workshop

This is a typical poor student's answer to an exam question. The comments explain what is wrong with the answers and how they can be improved. The examiner's mark scheme is given below.

(a) Describe how you would produce and observe an emission line spectrum in the laboratory. (2)

You would look at a discharge bulb through a slit 0/2

> The candidate has incorrectly described it as a bulb rather than a discharge lamp, and has indicated a slit rather than a diffraction grating.

(b) Describe what the spectrum would look like. (1)

A series of lines 1/1

> While this is a very simplistic description, it is adequate for 1 mark. If more marks were allocated for the question, then a better description would be: "a series of discrete bright lines against a dark background."

(c) Explain the origin of emission line spectra (3)

***When the electrons in an atom change energy the line is emitted.* 1/3**

> The candidate has shown understanding of energy change , but given no idea of quantized levels.

(d) Explain how observation of absorption spectra helps to determine the elemental make-up of a star. (4)

***Each line represents a particular element, so you can tell which elements are there.* 1/4**

> *The candidate has some understanding of the link between the lines and the element, but this is obviously insufficient for 4 marks*

Examiner's Answers

(a) *You would view a gas discharge lamp with a diffraction grating.*

(b) *The spectrum is a series of discrete bright lines against a dark background.*

(c) *Energy levels for the electrons in the atom are quantized. When an excited electron drops back from a higher level to a lower level, the energy is emitted as a photon of frequency given by: $\Delta E = hf$.*

(d) *Absorption spectra are produced when white light passes through a cooler vapour (such as the atmosphere of a star). Dark lines appear where bright ones would have been in the emission spectrum for a particular element, so comparison with known element emission spectra identifies the elements.*

Typical Exam Question

(a) Decribe the appearance and origin of an emission line spectrum. (5)

(b) Discus the similarities and differences between emission spectra and absorption spectra. You may be awarded a mark for the clarity of your answer. (5)

(a) *An emission line spectrum consists of discrete bright lines against a dark background. It arises because electrons in the atom cannot take any value of energy, only certain allowable levels. In a hot vapour, the electrons are excited into higher energy levels and when they drop back to the ground state in stages, the energy difference between levels is emitted as a photon of frequency given by $\Delta E = hf$, where ΔE is the energy difference, h is Planck's constant and f the frequency.*

(b) *Both emission and absorption spectra consist of discrete lines at certain frequencies, but the absorption spectrum has bright lines against a dark background at the same frequencies which the emission spectrum has as bright lines against a dark background.*
Both occur because of electron movement between allowable levels, but emission are due to excited electrons dropping down into lower levels, whereas absorption are due to electrons being excited into higher levels. Emission occurs from hot vapours, whereas absorption occurs when white light (all frequencies) passes through cooler vapour.

Questions

1. What is an emission line spectrum?

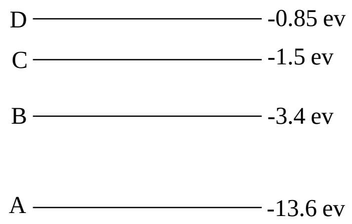
2. Why does an absorption line spectrum occur when white light passes through a cooler vapour?

3. How can observation of absorption spectra be used to identify the elements present in the atmosphere of a star?

4. (a) What is meant by "Red Shift" of line spectra?
   (b) Explain how the red shift of the line spectra of distance galaxies provides evidence to support the Big Bang theory.

5. Explain how emission spectra support the idea of quantization of energy levels.

6. The diagram shows some of the energy levels for atomic hydrogen.



   (a) Calculate the wavelength of the line which would appear in a line spectrum for the transition between the levels marked A and C.

   (b) Which transition represents a photon **absorbed** with the shortest wavelength.

   (c) Which transition represents a photon **emitted** with the longest wavelength.

Answers

1. See text.

2. When white light passes through a cooler vapour, frequencies appropriate to allowable transitions between energy levels in the atom are absorbed and electrons go into higher energy levels. Later, they drop back, but the photons are emitted in all directions, whereas the original energy was absorbed from the forward direction, so the specific frequency appears darker.

3. The frequencies of absorption lines in the spectra from stars can be compared with the emission lines in spectra of known elements and the elements in the atmosphere of the star identified.

4. (a) Red Shift is the slight shifting of known frequencies in the absorption spectra of distant stars to lower values (longer wavelength).

   (b) The most likely explanation for the red shift is that the source is moving away (Doppler effect). This implies that galaxies are now moving away from one another, i.e. they were originally all in the same place – Big Bang theory.

5. From a study of the Lyman series of lines in a hydrogen spectrum, possible values for the energy levels can then be worked out. These values can then be used to predict other series which should exist. Good agreement between theory and observation confirms the theory.

6. (a) $\Delta E = (13.6 - 1.5) \times 1.6 \times 10^{-19}$J

   so, $f = \dfrac{12.1 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$, $c = f\lambda$

   so $\lambda = \dfrac{3 \times 10^{8} \times 6.63 \times 10^{-34}}{(12.1 \times 1.6 \times 10^{-19})} = 1.03 \times 10^{-7}$m

   (b) $A \rightarrow D$. In absorption, the electron is excited to a higher level. Shortest wavelength is the highest frequency, therefore the largest energy gap.

   (c) $D \rightarrow C$. In emission, the electron drops back to a lower level. Longest wavelength is lowest frequency, therefore the smallest energy gap

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