Question 20 **(20 marks)**

Restoring The Night Watch

Rembrandt's *The Night Watch* was painted in 1642. But there is something odd about the name 'The Night Watch': it was not the name of the original painting. After it was restored, it became obvious that it was a daytime scene.

By the end of the 18th century, the painting had accumulated so many layers of varnish and dirt that it looked like the scene took place at night – and hence, it was misnamed 'The Night Watch'. The Rijksmuseum in Amsterdam carried out the largest research and restoration project ever. With the aid of X-ray fluorescence spectrometry, expensive paintings can be investigated harmlessly before restoration. This ensures sophisticated preservation of valuable art objects. It also allows the paintings to be restored securely in the buildings where the public can still enjoy them.

Depending on its energy, the X-ray beam penetrates into different depths of the painting's surface. This allows us to examine different layers of paint and even detect corrections made by Rembrandt without having to remove any paint. It is already known today that Rembrandt lengthened lances (spears) and changed the positioning of the people in the picture.

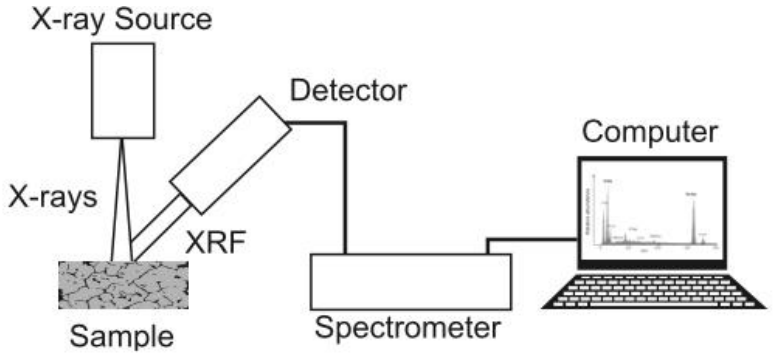


Figure 1: Schematic of process of X-ray fluorescence spectrometry

The spectrometer analyses the specific wavelengths of light given off by each sample of paint. It produces a printout similar to the one in Figure 2 showing the abundance of each wavelength emitted versus their energies.

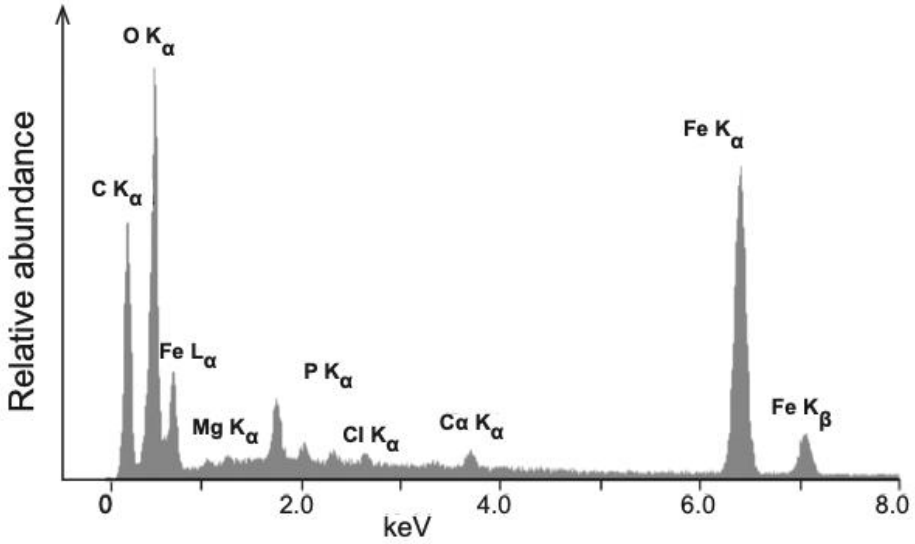
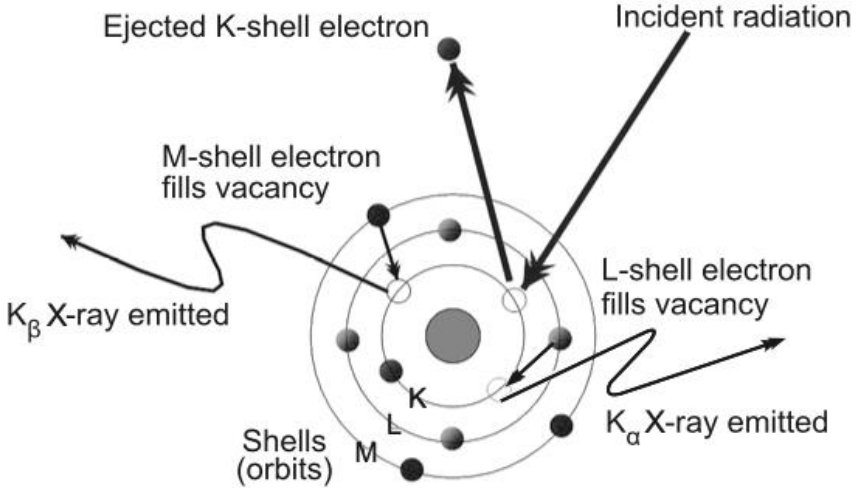


Figure 2: The relative abundance of energies of emitted photons

X-ray fluorescence analysis (XRF) is based on the detection of the fluorescence produced after the sample is bombarded with X-rays. Inner electrons are ejected by the incoming X-rays and then other electrons in higher energy shells cascade downward in smaller steps, emitting photons with specific wavelengths corresponding to the energy difference between shells. This fluorescence radiation is element-specific as the energy of each shell 'n' is given by:

$$E_n \propto \frac{Z^2}{n^2}$$

where Z is the charge on the nucleus, which is directly proportional to the number of protons in the nucleus. (For the K shell n = 1, for the L shell n = 2, and for the M shell n = 3.)



The main spectral lines correspond to electron transitions to the K shell. Transitions from the L shell to K shell produce K_α photons and those from the M shell to K shell produce K_β photons. This process is described in Figure 3.

(a) List **two** properties of X-rays that make them suitable for X-ray fluorescence spectrometry. (2 marks)

One: _____

Two: _____

(b) Explain how we now know that Rembrandt's original painting had lances of different length and some of the people were in different positions. (2 marks)

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(c) Give **two** advantages of using X-ray spectrometry to analyse old paintings. (2 marks)

One: _____

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Two: _____

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(d) Explain why the fluorescent radiation is element specific. (3 marks)

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(e) (i) Estimate the values of the M and L energy shells relative to the K shell for iron (Fe) displayed in Figure 2 and place them in the corresponding spaces below. (3 marks)

M _____ eV

L _____ eV

K 0 eV

(ii) Estimate the wavelength of the photon given off when an electron falls from the M shell to the L shell in an iron atom. (4 marks)

Answer _____ m

(iii) To which part of the electromagnetic spectrum does this wavelength belong? (1 mark)

(f) How would the graph in Figure 2 change if the operators of the spectrometer increased the power of the X-ray beam while keeping the wavelength constant? Explain your answer.

(i) Change (1 mark)

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(ii) Explanation (2 marks)

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