

If the theory of the "inverse photoelectric effect" is valid then Einstein's assumption of 1905, that both emission and absorption are "quantised", must be tested in relation to Planck's formula for photo-electron emission

$$w = h\nu \text{ joules}$$

where w is the energy associated with each quanta, ν is the frequency of radiation and h is Planck's constant.

Since $\nu = c/\lambda$ for electromagnetic radiation where c is the velocity of light, and $w = Ve$, the maximum energy that can be acquired by any electron within the X-ray tube system, then

$$Ve = hc/\lambda \quad \text{or} \quad h = V\lambda \left(\frac{e}{c}\right)$$

D15.9 Calculate the mean value for $V\lambda$ from D15.8 and evaluate h .

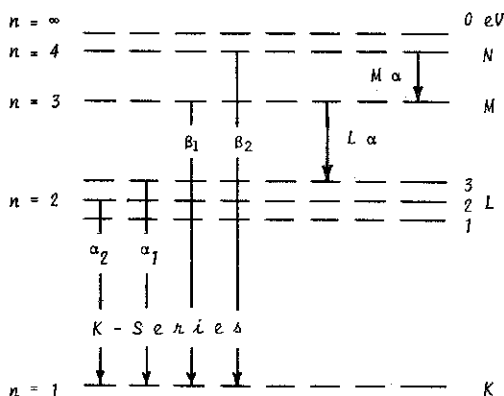
$$(e = 1.60 \times 10^{-19} \text{ coulombs}; \quad c = 3.00 \times 10^8 \text{ m sec}^{-1})$$

Compare with the international value for h of

$$6.62 \times 10^{-34} \text{ joule-sec}$$

The difference between the accepted standard value and the evaluated result for h of about 5% is well within experimental limits and illustrates why the 'inverse photo-electric effect' is considered to be a very accurate method of determining h , the fundamental constant in the Quantum Theory.

It is assumed that previous studies of optical spectra have established that "characteristic lines" in the visible region of the electromagnetic spectrum are emitted from atomic energy-levels of high principal quantum number, the N, O, P and Q levels; the relatively much shorter wavelengths of the characteristic K β and K α lines indicate that these shorter emissions are due to electron transitions at energy-levels of low principal quantum number. Any electron from the X-ray tube filament having sufficient energy to eject a K electron in a collision process will ionise the Copper atom; the ionised atom will revert to its stable state through electron transitions, each transition being accompanied by the emission of a photon of equivalent energy.



By definition, the K β emission results from transitions from the N and M levels to the K level and K α from transitions from the L to the K level [see para. D19]; the N and M levels have a greater energy difference with respect to the K level than does the L level and hence the wavelength of the K β photon is shorter and more energetic than that of K α . But the closer proximity of the L and K levels results in more frequent transitions than for the N or M levels and hence there is a greater "population" of K α exhibited by the relative intensities of the peaks 3 and 4 of graphs D14.7 and 8. [See also para. D19.7].

The Bragg experiment has established that a crystal can be used to demonstrate the co-operative interference of X-rays; the wavelength limit of the continuous "white" spectrum is dependent uniquely on the energy imposed upon the electrons by the potential difference between the electron emitting filament and the anode, regardless of its material; the "characteristic" line spectrum, superimposed upon the white spectrum is due to the elemental composition of the anode and the energy-levels associated with its individual electron system.

The lines are unique to emission from a Copper target and are thus termed CuK β and CuK α emission lines.

Spectral analysis by the Bragg technique can accurately evaluate a) an unidentified voltage, using both a known crystal and anode material, b) an unknown crystal structure using an identified voltage and anode material and c) the chemical composition of a material serving as an anode to emit characteristic radiation, using an established crystal and an accurately defined voltage.

The process of X-ray emission is such that the wavelength may well overlap both the ultra-violet and the Gamma regions of the broad electromagnetic spectrum; in the "Teltron Approach to Atomic Physics" the phenomenon of Gamma radiation has yet to be studied.

By its mode of emission X-radiation is therefore defined, through the "inverse photoelectric effect", and not by wavelength; "ultra-violet" radiation results from classical photoelectric events and "Gamma" radiation from nuclear disintegrations.

However, consequent upon the similarities between diffraction of optical and X-ray wavelengths, the student will surely anticipate 'absorption' effects in X-ray, as in optical, spectra.

D16 - X-RAY ABSORPTION (1 HOUR)

KIT 582	30 kV	80 μ A	NORMAL LAB
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- D16.1 Locate the NaCl crystal in the crystal post as in 14.1.
- D16.2 Mount the Auxiliary Slide Carriage in Mode H (see Part I, para 10.4) using the 1mm slot Primary Beam Collimator, vertical. Locate the Slide Collimator (3mm slot) 562.016 at E.S.4.
- D16.3 Position Slide Collimator (1mm) 562.015 at E.S.18 and the G.M. Tube Holder assembly at E.S.26; connect the G.M. Tube to a Scaler; due to the low count rates of this experiment, counts should be recorded over at least 10 second durations; the longer the counting period the greater the accuracy of the results; it is also advisable to monitor the tube current and adjust as necessary to 80 μ A.

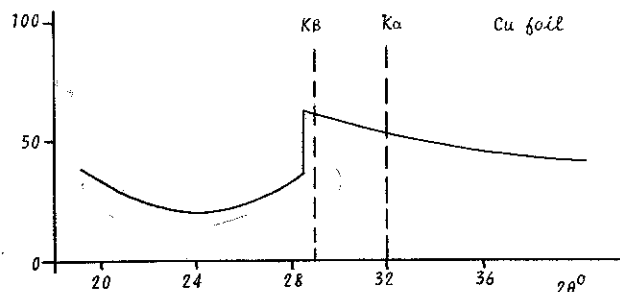
Ensure that 30kV is correctly selected.

- D16.4 Tabulate counts, I_0 from 20 $^\circ$ (2 θ) to 40 $^\circ$ at 1 $^\circ$ intervals.

$2\theta^\circ$	I_0 cps	I_{Cu} cps	I_{Cu}/I_0 %
20			
21			
22			

- D16.5 Locate the Copper Filter 564.006 at E.S.2 and tabulate counts I_{Cu} .
- D16.6 Calculate the ratio I_{Cu}/I_0 and plot as a Percentage Transmission against angle 2θ .

Transmission %



Observe that the whole spectrum has been reduced in intensity but that the expected "self-reversal" of the $K\beta$ and $K\alpha$ lines is not evident; a very abrupt discontinuity is revealed however at a wavelength just shorter than the $K\beta$ line.

- D16.7 From the graph, determine the angle 2θ at which this discontinuity occurs and calculate the equivalent wavelength in accordance with the Bragg equation:

$$\lambda = 2d \sin \theta$$

The Copper Foil interposed at E.S.2 has a finite thickness, 12.5×10^{-6} metres and, applying the Linear Absorption Co-efficient as studied at D10.14 some absorption of the spectrum must be expected.

That Copper does not 'reversibly' absorb its own characteristic emission lines $K\beta$ and $K\alpha$ is in agreement with the theory outlined in the comments following D15.9. To ionise an atom of the Copper target in the tube any electron from the filament must have sufficient energy to liberate an electron in the K level or indeed the L level for $L\beta$ or $L\alpha$ emission not detectable with the compact geometry of the Tel-X-ometer. Thus, in hypothetical terms:

$$W_0 \geq W_k \rightarrow \infty = -10 \times 10^3 \text{ eV.}$$

Following an M to K electron transition a $K\beta$ photon is emitted having energy W_{m+k} or -9.9×10^3 eV (ie $-10,000 + 100$ eV); there is therefore a relatively small energy difference of 100 eV.

The discontinuity occurs at a wavelength of 0.138 nm (from D16.7) which is just shorter in wavelength than the $K\beta$ emission (about 0.140 nm from D14.9) and it is evident therefore that a "classical photoelectric effect" has occurred wherein some photons in the primary X-ray beam have sufficient energy to ionise the Copper atoms in the foil placed at E.S.2.

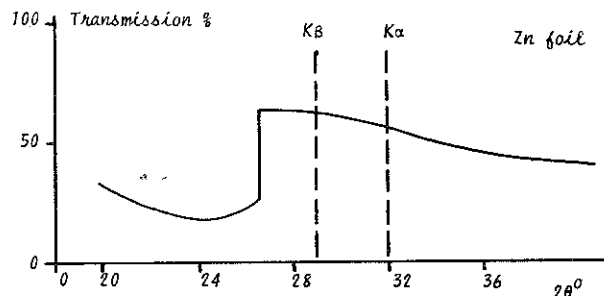
Furthermore, the value of the wavelength indicates that the incident photons must be a component part of the "white" radiation; the inference is therefore that the Copper foil will exhibit the "absorption edge" when exposed to radiation containing energies equivalent to 0.138 nm, regardless of the material of the source.

The discontinuity is thus unique to the system and is referred to as the CuK Absorption Edge.

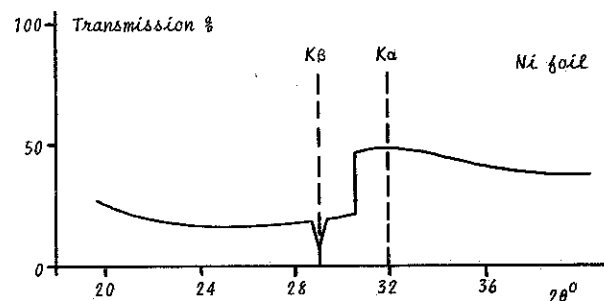
Since the elements in the periodic table have different energy-level structures and densities the student could now

expect to find an element which will discreetly absorb Copper K emission by a systematic study using foils of different elements, but equal thickness.

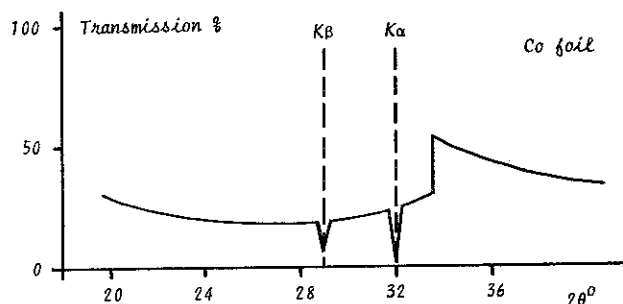
- D16.8 Remove the Copper Filter from E.S.2 and replace with the Zinc Filter 563.009.
Repeat 16.5, 16.6 and 16.7.



- D16.9 Remove the Zinc Filter and replace with the Nickel Filter 564.004.
Repeat 16.5, 16.6 and 16.7.



- D16.10 Remove the Nickel Filter and replace with the Cobalt Filter 564.008.
Repeat 16.5, 16.6 and 16.7.



Observe that only the Cobalt Foil has absorbed or "filtered out" both the CuK emission lines but that Nickel has dramatically discriminated between the $K\beta$ and $K\alpha$ radiation.

Clearly the absorption of X-rays is dependent not only on the thickness of the absorbing material but also on the nature of the material itself.

The Linear Absorption Co-efficient is not therefore sufficiently definitive for X-ray purposes, especially with thin foils where the effect due to the material is greater than that due to thickness.